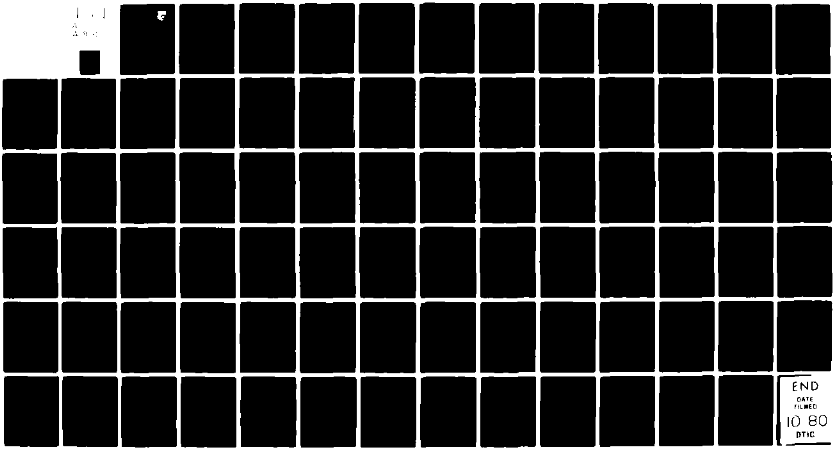
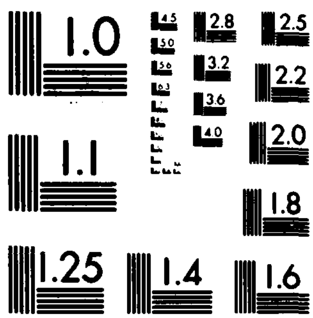
AD-A089 629 SYSTEMS RESEARCH LABS INC DAYTON OH AEROSYSTEMS GROUP F/G 14/2
AIRCRAFT ENGINE NACELLE FIRE TEST SIMULATOR. VOLUME I. TECHNICA--ETC(U)
APR 80 K O BALL, D B BURNSIDES, R D HEGELE F33615-76-C-2084
UNCLASSIFIED AFWAL-TR-80-2055-VOL-1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFWAL-TR-80-2055
VOLUME I

AIRCRAFT ENGINE NACELLE FIRE TEST SIMULATOR
VOLUME I: TECHNICAL

Aerosystems Group
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

May 1980

TECHNICAL REPORT AFWAL-TR-80-2055, VOLUME I
FINAL REPORT FOR PERIOD September 1976 to April 1980

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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ROBERT D. SHERRILL
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Engine Compartment
Engine Bay

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the design, installation, and initial checkout of the Aircraft Engine Nacelle Fire Test Simulator. This facility was designed to realistically reproduce the environments and combustion-related phenomena encountered within an engine nacelle. The facility provides both heating and cooling of the inlet air, heating of the engine case, control of air velocity and air pressure, and for the injection of fluids, combustibles or extinguishants. → over

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The Report presents the final implementation of the system and details the hardware installation, the control system, and the software needed to provide integrated control, safety, and data acquisition. Only limited checkout was possible due to the failure of the air compressor and the cleaning and modification efforts required to return the system to a safe operating level. Tests did verify the operation and control of all facility systems. The Report was prepared in three volumes as follows:

Volume I - Technical
Volume II - Control System
Volume III - Reduced Drawings

PREFACE

This report documents the results of the work efforts under Contract No. F33615-76-C-2084, "Aircraft Engine Nacelle Fire Test Simulator." This contract is monitored by the Air Force Aero Propulsion Laboratory (AFWAL/POSH) with Mr. Robert G. Clodfelter as the USAF Project Engineer. This effort was funded by AFAPL, the Federal Aviation Administration, the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS), the Army, and the Navy. The work was conducted under Program Element 62203F, Project 3048, Task 304807, Work Unit 30480771.

The report has been prepared in three volumes as follows:

- Volume I - Technical
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Section I
INTRODUCTION

A. GENERAL

Due to the co-location of flammable fluids and thermal ignition sources, an inherent fire risk potential exists in aircraft engine nacelle compartments. The ignition threat has been minimized by preventive measures, such as insulating lines and provisions for ventilation, and by effective fire control for some aircraft through use of fire detection and extinguishing systems. For current aircraft, these techniques have resulted in acceptable installed engine fire protection. As aircraft and engine performance increases, the operating environments generated within the nacelle and adjacent compartments increases the fire hazard potential in these areas and will require delineation of effective fire prevention and control measures.

To satisfy the critical need for data to address fire prevention and control techniques, this program was initiated in September 1976 to create a ground test facility which will realistically and practically reproduce the environments and combustion-related phenomena encountered within the nacelle.

The phenomenon, to be simulated by the facility for research purposes, is extremely complex. The process is one of heat and mass transfer with combustion in an annulus duct for which the annulus area changes significantly along the duct length. The important aircraft engine nacelle parameters required to be simulated for research investigations of fire detection and overheat systems, fire extinguishing systems, and characterization of basic fire hazards are:

- Air Velocity
- Air Pressure
- Air Temperature
- Engine Case Temperature

- Nacelle Geometry
- Injected Fluids/Combustibles/Extinguishers

The facility costs and power requirements for a full-scale simulator with airflow velocities up to 400 feet/second, air temperatures approaching 800°F, and air pressures down to 0.6 psia, would be prohibitive. However, exceptional capabilities for research can be achieved with only limited air pressure, air temperature, and airflow velocity ranges incorporated in a sectional nacelle that has growth potential to a full annulus. This quasi-subscale approach was used in this program.

The program was conducted in a normal progression of five tasks, i.e., preliminary and final design, fabrication, installation, and checkout/documentation, with major program objectives ranked in the following basically descending order:

1. Technical Goals
2. Safety
3. Costs
4. Reliability and Maintainability (R&M)
5. Schedules

The problems encountered during the program may be summarized as those relating to necessary iterations in the design phase between the technical goals, safety, and cost; e.g., the definition of the exhaust system not only from a safety standpoint but also to comply with environmental constraints; cost and delivery of purchased equipment and installation subcontracts, and finally malfunction of equipment during subsystem checkout; specifically, the schedule impact from the high pressure air compressor failure.

Data acquisition and control software was developed for the AENFTS and was submitted as a stand alone document. It provides an overview of the hardware interface configuration as well as describing the overall system software flow of the functional software modules.

The facility resulting from this program provides the USAF a powerful tool for fire prevention and control studies to assure timely transition of R&D engine nacelle fire protection technology into operational aircraft.

B. PERFORMANCE GOALS

An overview of the simulator and its associated equipment capabilities, as compared to the Contract Work Statement performance goals and baseline concepts, is presented in Table I-1. Without exception, the desired capabilities are met or exceeded by the simulator design.

Typical performance envelopes for the simulator are given in Figures I-1 and I-2 in terms of nacelle inlet pressure, temperature, and velocity. The Statement of Work boundaries are also shown in Figure I-1. The curves of both Figures are based on the following relations for inlet conditions:

$$V = \frac{\dot{M}R}{PA} T, \text{ ft/sec}$$

$$T = \frac{0.948(KW)}{\dot{M}C_p} + T_A$$

where:

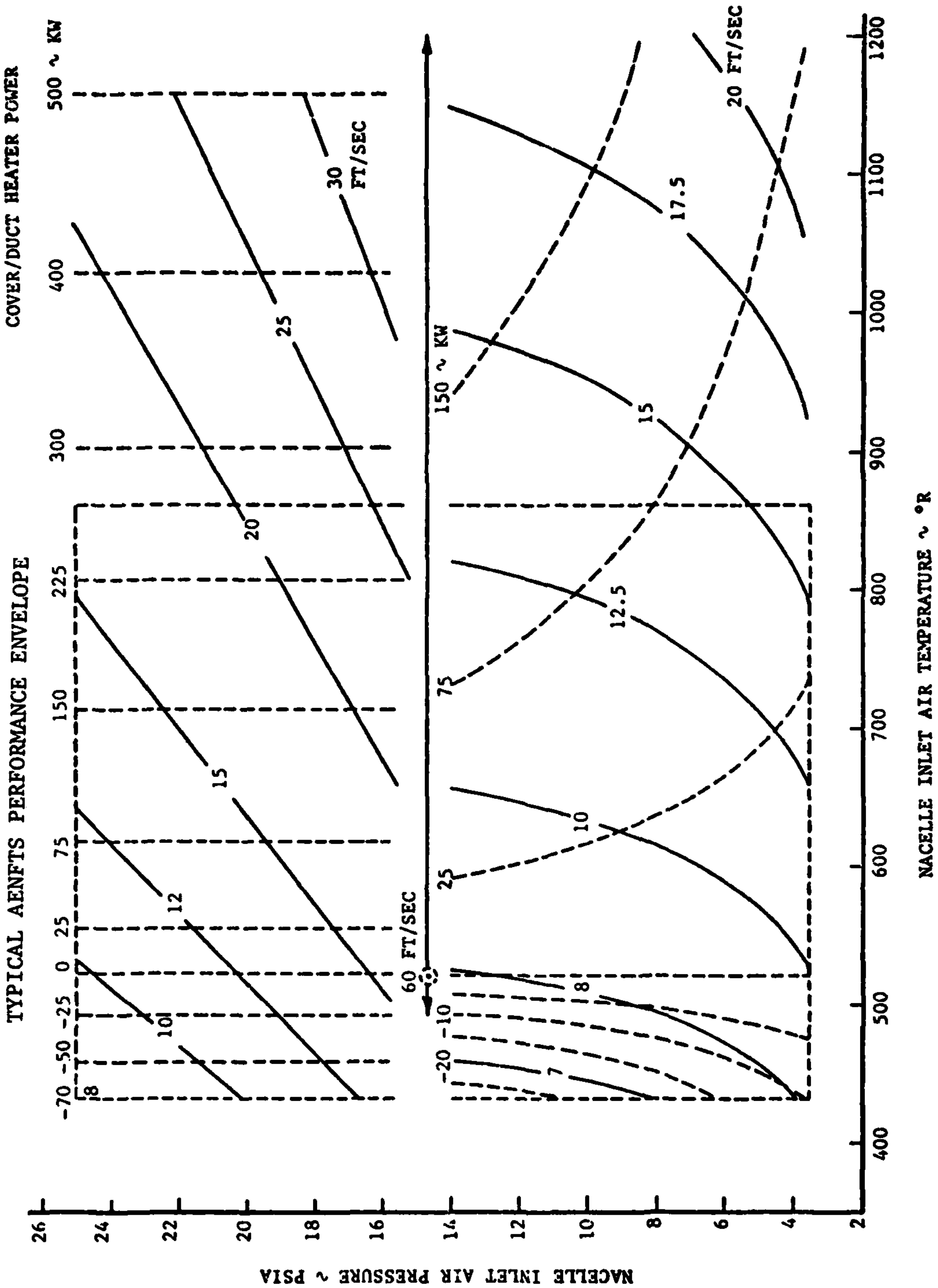
- V = inlet velocity, ft/sec
- $\dot{M}$ = inlet mass flow, lb/sec
- R = gas constant = 53.3 ft/°R
- P = inlet pressure, lb ft^2
- C_p = specific heat 0.24 BTU/lb°R
- A = unrestricted cross-sectional area = 2.44 ft^2
- T = inlet temperature, °R
- KW = kilowatts
- T_A = Ambient temperatures, °R

AIRCRAFT ENGINE NACELLE FIRE TEST SIMULATOR

CAPABILITY OVERVIEW

Item/Function	Work Statement	Design
General:		
Location	I-Bay (Bldg. 71)	=
Safety	Personnel and Equipment	=
Maintainability	✓	=
Durability	✓	=
Portable	✓	=
Access/Egress	✓	$\geq$
Computer Interface	MODCOMP II	=
Performance:		
Inlet Air Temperature	-30°F to 400°F	-40°F to 1000°F
Inlet Air Pressure	3.5 psia to 25 psia	3.5 psia to 25 psia +
Air Flow Rate/Inlet Velocity Accuracy	$\pm$ 5%	$\leq \pm$ 5%
Engine Case Temperature	Up to 1500°F	$\geq$1500°F
Test Duration (Hi and Lo Pressure)	5 minutes	>20 minutes
Utility:		
Flexible Engine Case Heating	15" and 8" Radius	=
Windows in Test Section	✓	=
Test Section Access	✓	=
Movable Carriage	✓	=
Test Section Rotation	180°	=
Carriage Load Capability	3X	>3X
Other Air Flow Capability	✓	$\geq$
Transformer Rating	1.5 MW	2 MW
Control Panel	Graphic	=
Pollution Control	✓	$\geq$

TABLE I-1



TYPICAL AENFTS PERFORMANCE ENVELOPE
COVER/DUCT HEATER POWER ~ KW
NACELLE INLET AIR TEMPERATURE ~ °R
NACELLE INLET AIR PRESSURE ~ PSIA
FT/SEC

FIGURE I-1

OPERATING ENVELOPE
ATMOSPHERIC SYSTEM

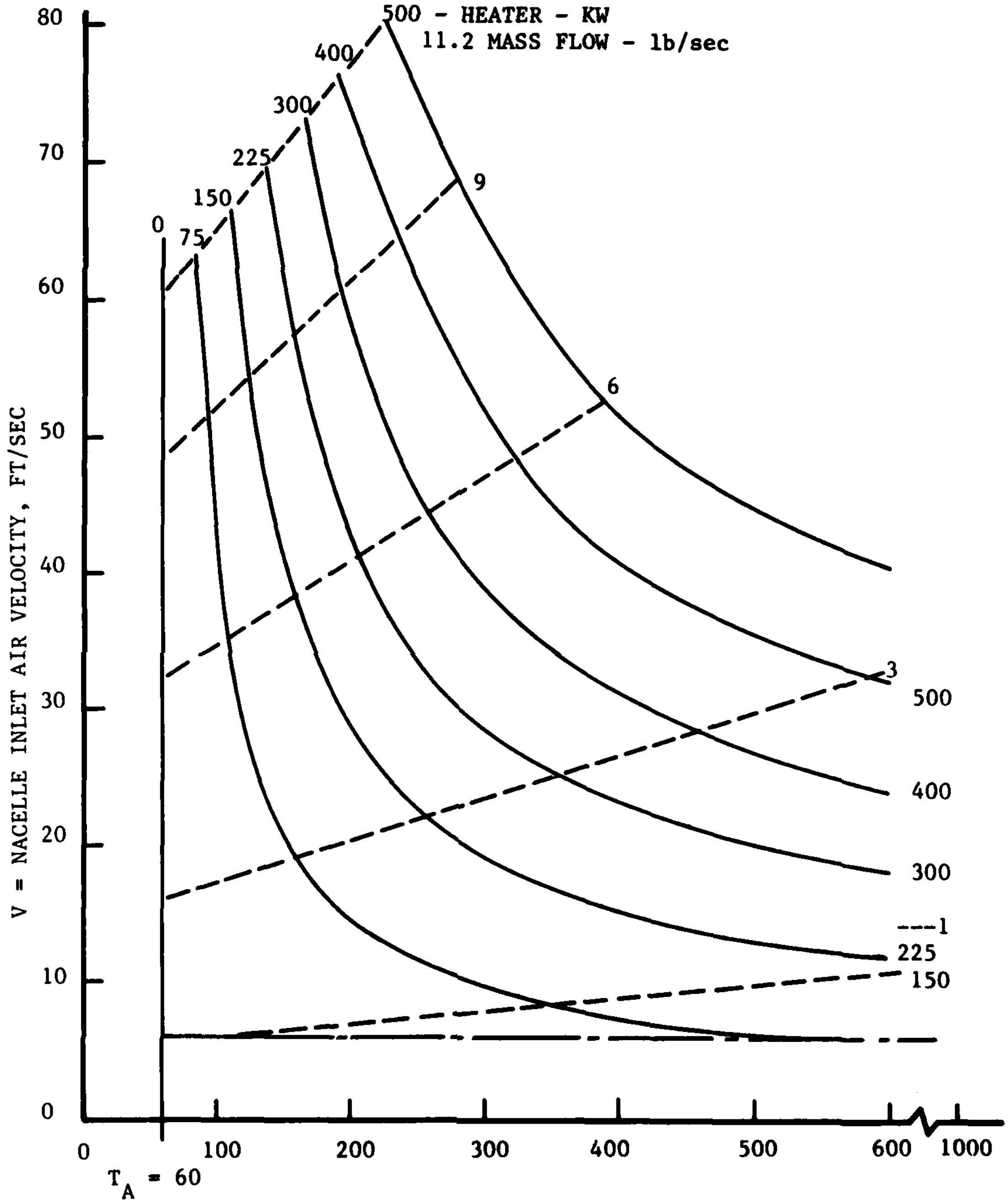


FIGURE I-2

The following sections present the details of the final design and represent the "as built" configuration. Also discussed are design changes which were required and implemented as a result of various subsystem tests or installation difficulties. The calibration and setup procedures are discussed and reviewed as are the results of the system tests.

The remaining volumes of this document present the details of the control and instrumentation system in a stand-alone volume for ease in system troubleshooting; the software used in the MODCOMP computer for system control and data acquisition; and a complete package of reduced drawings showing the as-built AENFTS mechanical and electrical configuration. For additional detail and backup data of various system components and their associated performance parameters, reference should be made to the MANUFACTURERS EXCERPTS for the AENFTS which have been submitted separately.

Section II
DESIGN

A. GENERAL

The Aircraft Engine Nacelle Fire Test Simulator (AENFTS) provides practical, realistic simulation of the environments and combustion related phenomena within an aircraft engine nacelle for research investigations of fire detection and overheat systems, fire extinguishing systems, and characterization of basic fire hazards. The following integrated simulator subsystems are used to achieve the range of temperature, pressure, and velocity requirements needed to achieve the performance goals of the program:

- Nacelle Test Section
- Engine/Nacelle Heating
- Air Delivery and Conditioning
- Air Exhaust and Pollution Control
- Control and Instrumentation (presented in Volume II)
- Auxiliary Equipment
  - Combustible fluid injection
  - Fire control and extinguishing
- Test Facility Interfaces
  - Electric power
  - Cooling water
  - Refrigeration System
  - Instrument Air

The inlet air/pressure simulation further dictates three major systems for the air delivery and conditioning subsystems as follows:

- Atmospheric System
- Low Pressure System (to 3.5 psia)
- High Pressure System (to 25 psia)

The general layout of the facility is shown in Figure II-1 while Figure II-2 is a System Schematic which synopsizes the simulator and its associated equipment. The next paragraphs will describe the design and operating methodology, where appropriate, of each of the simulator systems/subsystems.

B. NACELLE TEST SECTION

The test section is a two-radian sector of concentric cylinders. The inner cylinder has a 15-inch radius, and the outer cylinder a 24-inch radius which provides a nominal flow area of 2.44 square feet. The length of the three heated sections was established at 37 inches to facilitate installation of the radiant heater assemblies. An unheated inlet section of approximately 5 feet in length, together with an inlet transition, provides uniform flow in the nacelle test section. The inlet section transitions from a 24-inch diameter duct (3.1 square feet) to the 2.44 square feet test section. The last heated section in turn dumps into a 4-foot diameter plenum, which then transitions into a 24-inch diameter exhaust duct (Figure II-3). This entire test section assembly except for the plenum, is supported on a movable roll over frame assembly. The test sections, Figure II-4, were fabricated from type 30321 and 30347 stabilized stainless steel with a nominal 0.25 inch thickness Tungsten inert gas (TIG) welding with 30347 filler rod used to assemble the structure. These materials were selected since they are easily weldable and provide good stability and resistance to thermal stress during high temperature exposure. Further, they provide corrosion protection for the test sections. A 0.625 thick by 2 inch flange forms the end of each test section. To eliminate the necessity of making corner welds on the edges of the duct sections, 30321 stainless steel angles, were used. This assembly concept required butt welding which provided a stronger structure.

A summary of major results of the test section structural analysis is presented below. A detailed structural analysis can be found in Volume III of the AENFTS Final Design Report dated 14 June 1977.

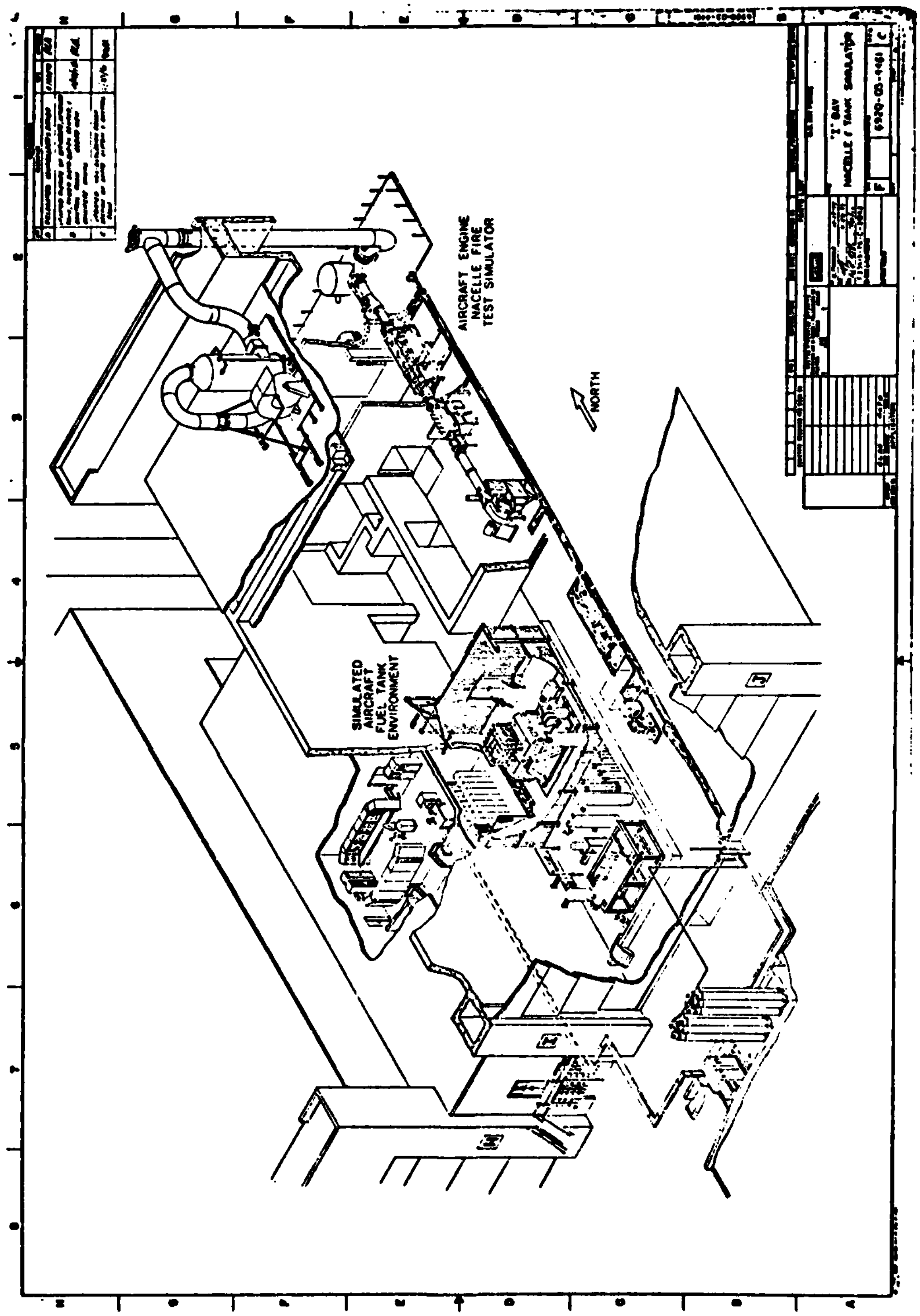
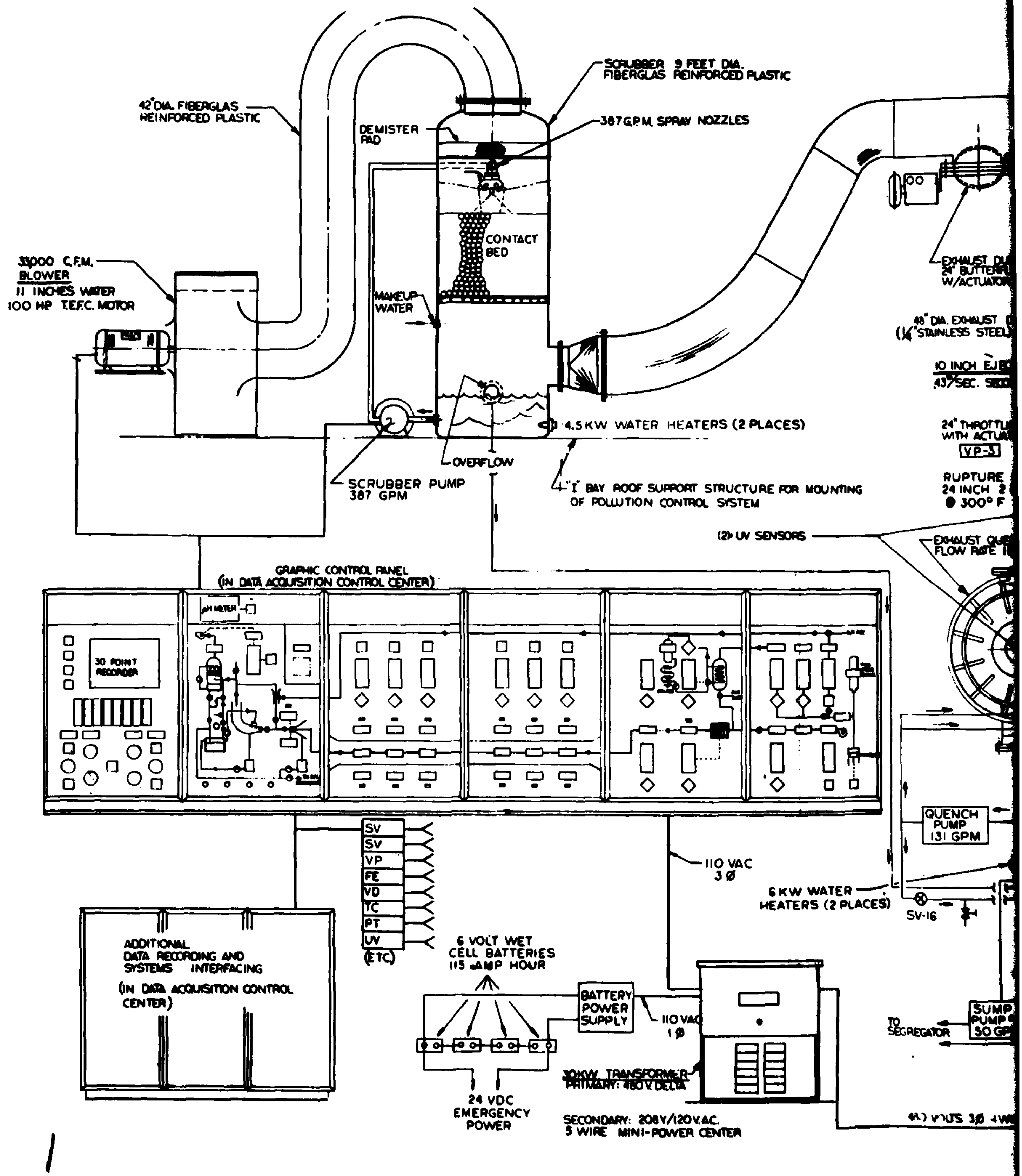
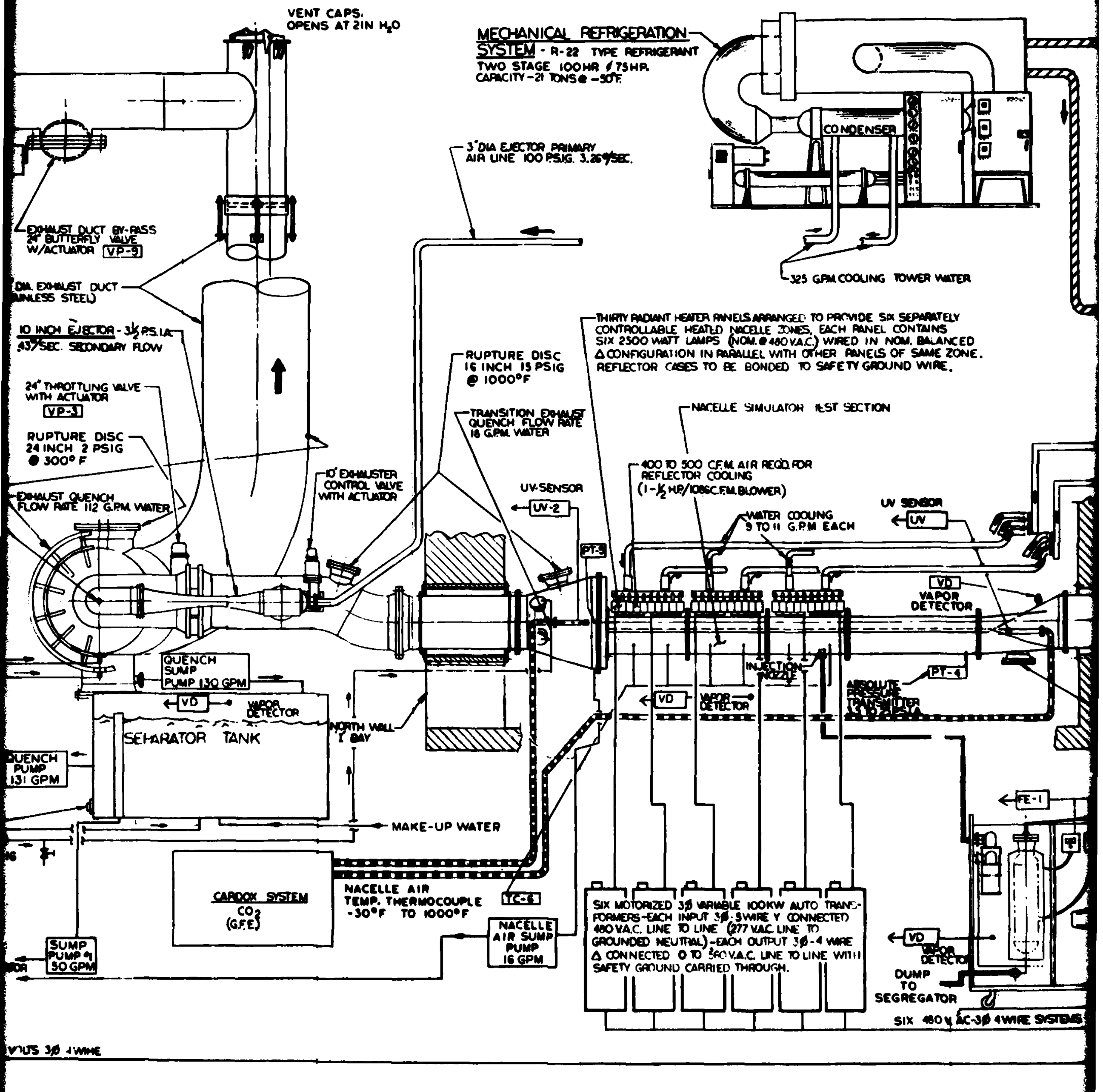

AIRCRAFT ENGINE NACELLE FIRE TEST SIMULATOR
SIMULATED AIRCRAFT FUEL TANK ENVIRONMENT
NORTH

FIGURE II-1

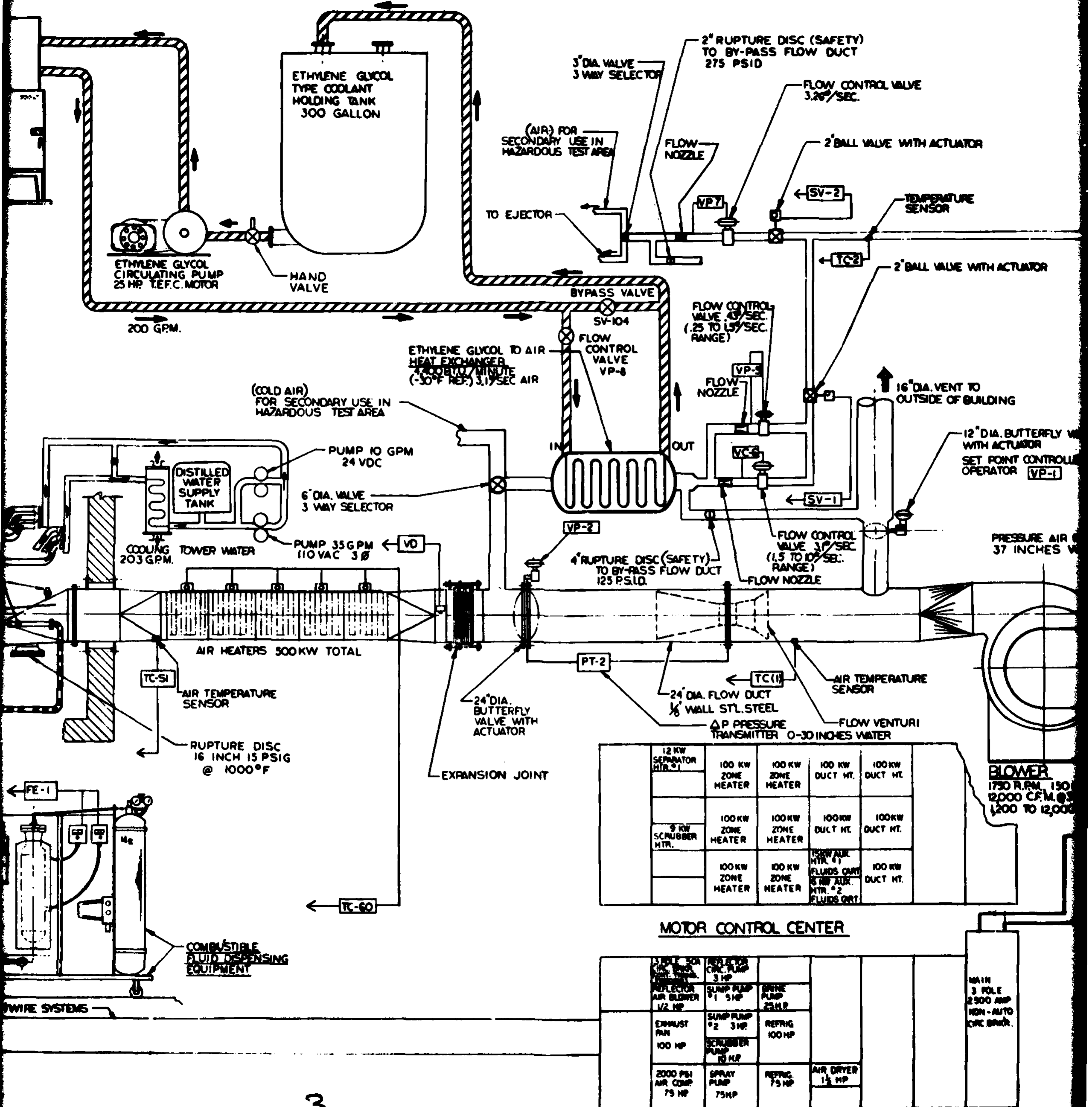


SCRUBBER 9 FEET DIA. FIBERGLAS REINFORCED PLASTIC
42" DIA. FIBERGLAS REINFORCED PLASTIC
387 G.P.M. SPRAY NOZZLES
DEMISTER PAD
CONTACT BED
33000 C.F.M. BLOWER
11 INCHES WATER
100 HP T.E.F.C. MOTOR
MAKEUP WATER
4.5 KW WATER HEATERS (2 PLACES)
OVERFLOW
SCRUBBER PUMP 387 GPM
"I" BAY ROOF SUPPORT STRUCTURE FOR MOUNTING OF POLLUTION CONTROL SYSTEM
(2) UV SENSORS
GRAPHIC CONTROL PANEL (IN DATA ACQUISITION CONTROL CENTER)
pH METER
30 POINT RECORDER
SV
SV
VP
FE
VD
TC
PT
UV
(ETC)
110 VAC 3 Ø
6 KW WATER HEATERS (2 PLACES)
SV-16
QUENCH PUMP 131 GPM
ADDITIONAL DATA RECORDING AND SYSTEMS INTERFACING
(IN DATA ACQUISITION CONTROL CENTER)
6 VOLT WET CELL BATTERIES 115 AMP HOUR
BATTERY POWER SUPPLY
110 VAC 1 Ø
24 VDC EMERGENCY POWER
30 KW TRANSFORMER PRIMARY: 480 V DELTA
SECONDARY: 208Y/120 V.AC. 5 WIRE MINI-POWER CENTER
TO SEGREGATOR
RUPTURE
24 INCH
300° F
VP-3

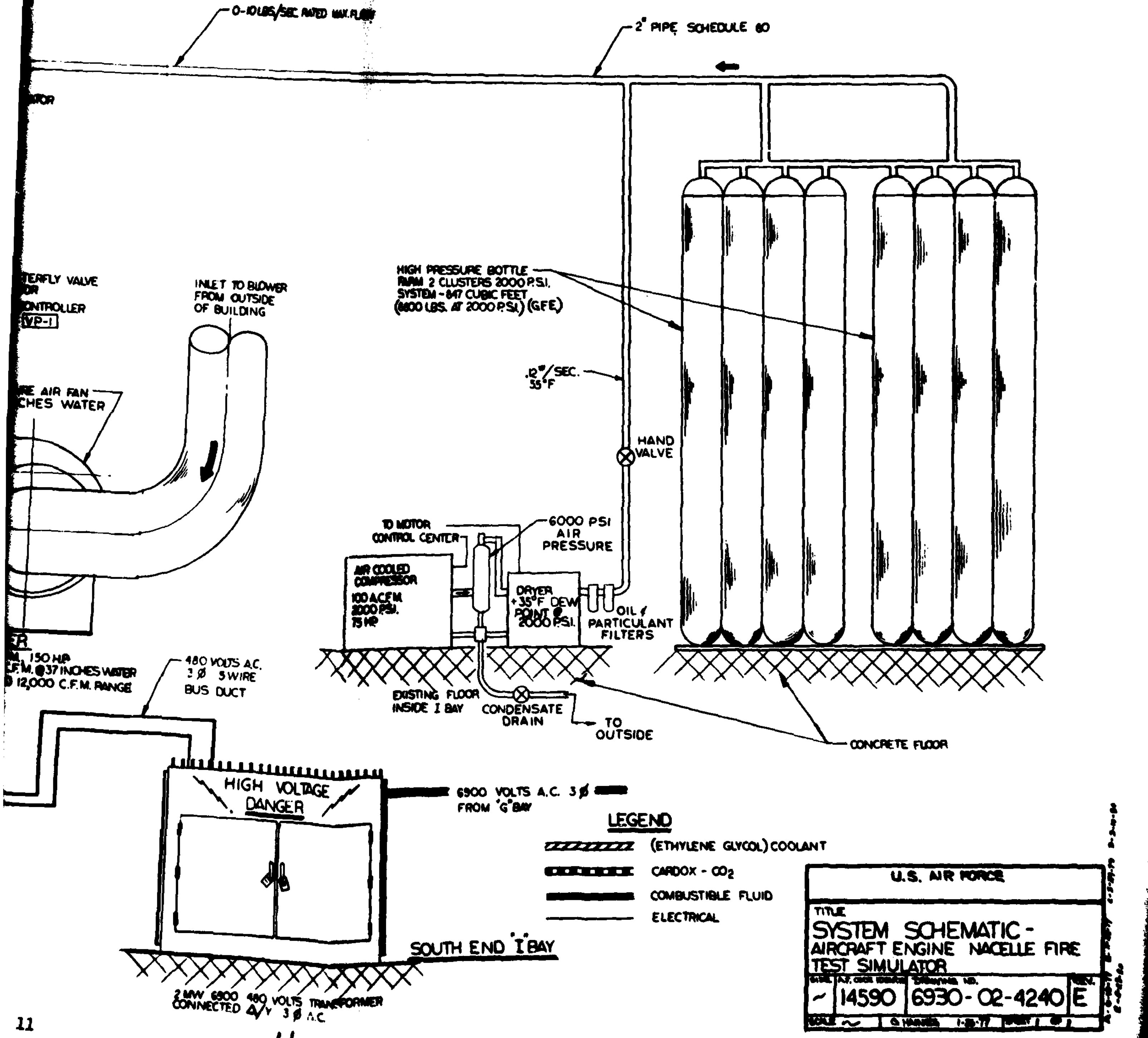


VENT CAPS. OPENS AT 2IN H_2O
MECHANICAL REFRIGERATION SYSTEM - R-22 TYPE REFRIGERANT
TWO STAGE 100HP / 75HP.
CAPACITY-21 TONS @ -50°F.
CONDENSER
325 GPM COOLING TOWER WATER
3" DIA EJECTOR PRIMARY AIR LINE 100 PSIG. 3.26#/SEC.
EXHAUST DUCT BY-PASS 24" BUTTERFLY VALVE W/ACTUATOR VP-9
DIA. EXHAUST DUCT STAINLESS STEEL
10 INCH EJECTOR - 3½ PSIA 43#/SEC. SECONDARY FLOW
24" THROTTLING VALVE WITH ACTUATOR VP-3
RUPTURE DISC 24 INCH 2 PSIG @ 300° F
EXHAUST QUENCH FLOW RATE 112 G.P.M. WATER
RUPTURE DISC 16 INCH 15 PSIG @ 1000°F
TRANSITION EXHAUST QUENCH FLOW RATE 18 G.P.M. WATER
10" EXHAUSTER CONTROL VALVE WITH ACTUATOR
UV-SENSOR
UV-2
PT-5
THIRTY RADIANT HEATER PANELS ARRANGED TO PROVIDE SIX SEPARATELY CONTROLLABLE HEATED NACELLE ZONES, EACH PANEL CONTAINS SIX 2500 WATT LAMPS (NOM. @ 480 V.A.C.) WIRED IN NOM. BALANCED Δ CONFIGURATION IN PARALLEL WITH OTHER PANELS OF SAME ZONE. REFLECTOR CASES TO BE BONDED TO SAFETY GROUND WIRE.
NACELLE SIMULATOR TEST SECTION
400 TO 500 C.F.M. AIR REQD. FOR REFLECTOR COOLING (1-½ H.P./1086 C.F.M. BLOWER)
WATER COOLING 9 TO 11 G.P.M. EACH
UV SENSOR
UV
VD
VAPOR DETECTOR
QUENCH SUMP PUMP 130 GPM
VD
VAPOR DETECTOR
SEPARATOR TANK
QUENCH PUMP 131 GPM
NORTH WALL 1 BAY
INJECTION NOZZLE
VD
VAPOR DETECTOR
ABSOLUTE PRESSURE TRANSMITTER
PT-4
MAKE-UP WATER
FE-1
CARDOX SYSTEM
CO_2
(G.F.E.)
NACELLE AIR TEMP. THERMOCOUPLE -30°F TO 1000°F
TC-6
NACELLE AIR SUMP PUMP 16 GPM
SUMP PUMP #1 50 GPM
SIX MOTORIZED 3Ø VARIABLE 100KW AUTO TRANSFORMERS-EACH INPUT 3Ø-5WIRE Y CONNECTED 480 V.A.C. LINE TO LINE (277 V.A.C. LINE TO GROUNDED NEUTRAL)-EACH OUTPUT 3Ø-4 WIRE Δ CONNECTED 0 TO 560 V.A.C. LINE TO LINE WITH SAFETY GROUND CARRIED THROUGH.
VD
VAPOR DETECTOR
DUMP TO SEGREGATOR
SIX 480 V AC-3Ø 4WIRE SYSTEMS
VOLTS 3Ø 4WIRE

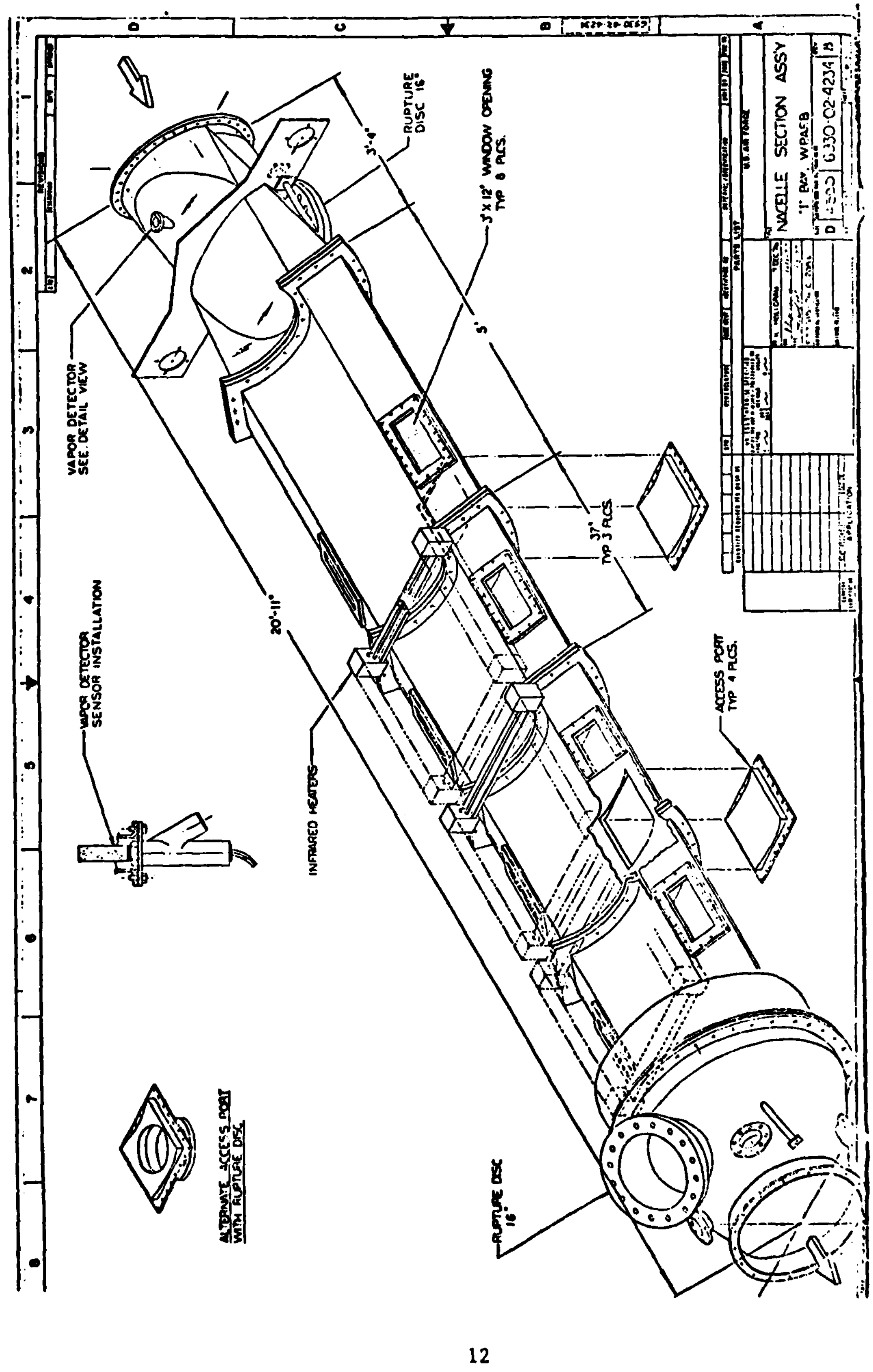
2


ETHYLENE GLYCOL TYPE COOLANT HOLDING TANK 300 GALLON
ETHYLENE GLYCOL CIRCULATING PUMP 25 HP. T.E.F.C. MOTOR
HAND VALVE
200 GPM.
BYPASS VALVE
SV-104
FLOW CONTROL VALVE VP-8
ETHYLENE GLYCOL TO AIR HEAT EXCHANGER
(COLD AIR) FOR SECONDARY USE IN HAZARDOUS TEST AREA
3" DIA. VALVE 3 WAY SELECTOR
2" RUPTURE DISC (SAFETY) TO BY-PASS FLOW DUCT 275 PSID
FLOW CONTROL VALVE 3.26/SEC.
(AIR) FOR SECONDARY USE IN HAZARDOUS TEST AREA
FLOW NOZZLE
2" BALL VALVE WITH ACTUATOR
TO EJECTOR
VP7
SV-2
TEMPERATURE SENSOR
TC-2
2" BALL VALVE WITH ACTUATOR
FLOW CONTROL VALVE 4/SEC. (.25 TO 1.5/SEC. RANGE)
VP-5
FLOW NOZZLE
16" DIA. VENT TO OUTSIDE OF BUILDING
12" DIA. BUTTERFLY WITH ACTUATOR
SET POINT CONTROLLER OPERATOR VP-1
PUMP 10 GPM 24 VDC
DISTILLED WATER SUPPLY TANK
6" DIA. VALVE 3 WAY SELECTOR
IN
OUT
VC-6
SV-1
COOLING TOWER WATER 203 GPM.
PUMP 35 GPM 110 VAC 3 Ø
VD
VP-2
4" RUPTURE DISC (SAFETY) TO BY-PASS FLOW DUCT 125 PSID.
FLOW CONTROL VALVE 3/SEC (1.5 TO 10/SEC. RANGE)
FLOW NOZZLE
PRESSURE AIR 37 INCHES W
AIR HEATERS 500 KW TOTAL
TC-S1
AIR TEMPERATURE SENSOR
RUPTURE DISC 16 INCH 15 PSIG @ 1000°F
24" DIA. BUTTERFLY VALVE WITH ACTUATOR
EXPANSION JOINT
PT-2
TC(1)
24" DIA. FLOW DUCT 1/8" WALL STL. STEEL
AIR TEMPERATURE SENSOR
Δ P PRESSURE TRANSMITTER 0-30 INCHES WATER
FLOW VENTURI
BLOWER
1750 R.P.M.
12,000 C.F.M.
1,200 TO 12,000
FE-1
TC-60
COMBUSTIBLE FLUID DISPENSING EQUIPMENT
WIRE SYSTEMS
12 KW SEPARATOR HTR.
100 KW ZONE HEATER
100 KW DUCT HT.
9 KW SCRUBBER HTR.
15 KW AUX. HTR. #1 FLUIDS CART
15 KW AUX. HTR. #2 FLUIDS CART
MOTOR CONTROL CENTER
REFLECTOR CIRC. PUMP 3 HP
REFLECTOR AIR BLOWER 1/2 HP
SUMP PUMP #1 5 HP
BRINE PUMP 25 HP
EXHAUST FAN 100 HP
SUMP PUMP #2 3 HP
SCRUBBER PUMP 10 HP
REFRIG. 100 HP
2000 PSI AIR COMP 75 HP
SPRAY PUMP 75 HP
REFRIG. 75 HP
AIR DRYER 1½ HP
MAIN 3 POLE 2500 AMP NON-AUTO CIRC. BRKR.

3


0-10LBS/SEC RATED MAX.FLOW
2" PIPE SCHEDULE 80
HIGH PRESSURE BOTTLE FARM 2 CLUSTERS 2000 P.S.I. SYSTEM - 847 CUBIC FEET (8800 LBS. AT 2000 P.S.I.) (GFE)
.12#/SEC. 35°F
HAND VALVE
6000 PSI AIR PRESSURE
TO MOTOR CONTROL CENTER
AIR COOLED COMPRESSOR 100 A.C.F.M. 2000 P.S.I. 75 HP
DRYER +35°F DEW POINT @ 2000 P.S.I.
OIL & PARTICULANT FILTERS
EXISTING FLOOR INSIDE I BAY
CONDENSATE DRAIN
TO OUTSIDE
CONCRETE FLOOR
ERFLY VALVE
OR
ONTROLLER
VP-1
INLET TO BLOWER FROM OUTSIDE OF BUILDING
RE AIR FAN
CHES WATER
ER
M. 150 HP
C.F.M. @37 INCHES WATER
D 12,000 C.F.M. RANGE
480 VOLTS A.C. 3 Ø 5 WIRE BUS DUCT
HIGH VOLTAGE
DANGER
6900 VOLTS A.C. 3 Ø FROM "G" BAY
2 MW 6900 480 VOLTS TRANSFORMER CONNECTED Δ/Y 3 Ø A.C.
SOUTH END "I" BAY
LEGEND
(ETHYLENE GLYCOL) COOLANT
CARDOX - CO_2
COMBUSTIBLE FLUID
ELECTRICAL
U.S. AIR FORCE
TITLE
SYSTEM SCHEMATIC -
AIRCRAFT ENGINE NACELLE FIRE
TEST SIMULATOR
14590
6930-02-4240
E
G HAINES 1-25-77

4



VAPOR DETECTOR
SEE DETAIL VIEW
RUPTURE
DISC 16"
3'-4"
3"x 12" WINDOW OPENING
TYP 8 PLCS.
3'
37"
TYP 3 PLCS.
20'-11"
VAPOR DETECTOR
SENSOR INSTALLATION
INFRARED HEATERS
ACCESS PORT
TYP 4 PLCS.
ALTERNATE ACCESS PORT
WITH RUPTURE DISC
RUPTURE DISC
16"
NACELLE SECTION ASSY
'I' BAY WPAFB
U.S. AIR FORCE
PARTS LIST

FIGURE II-3

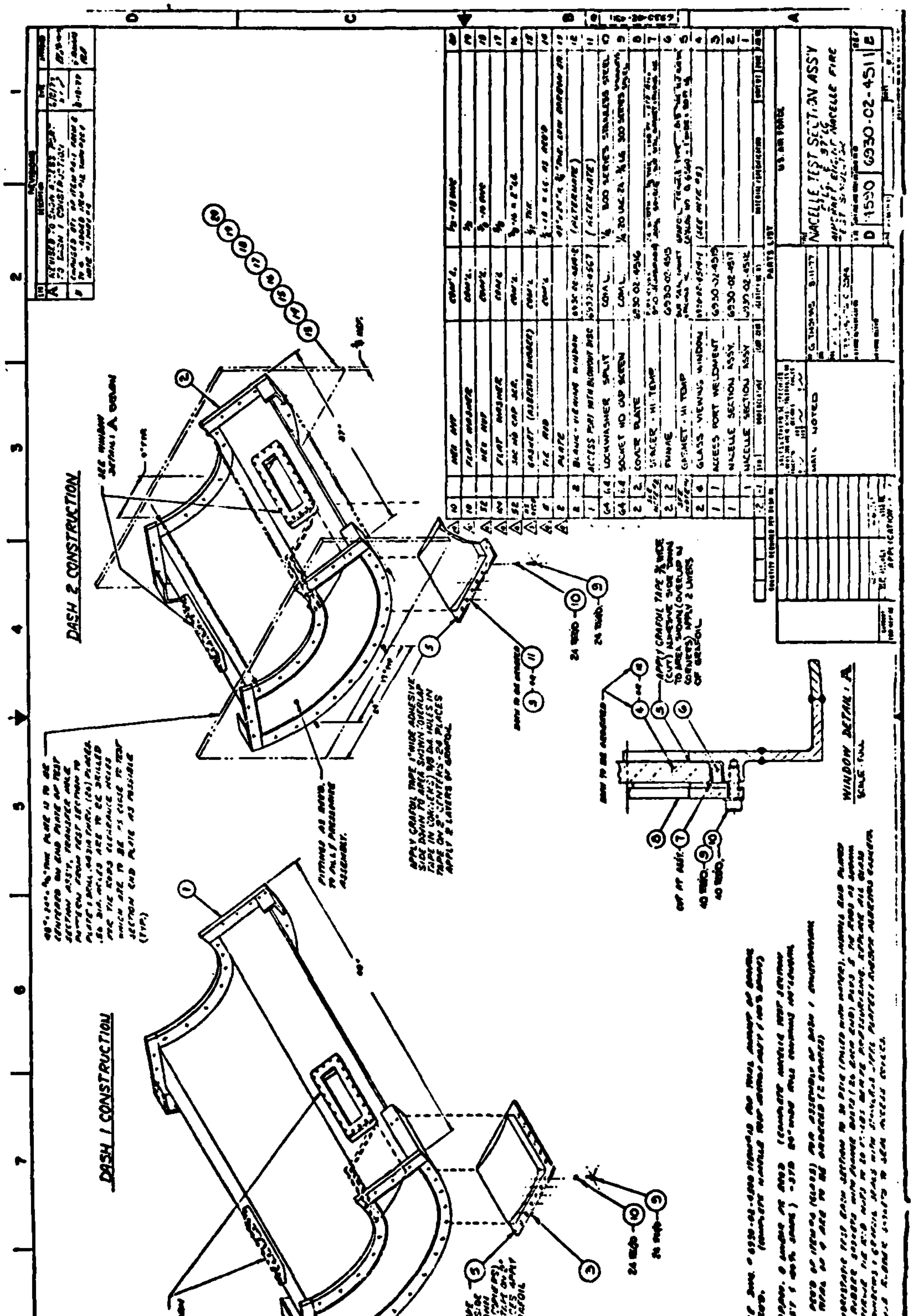

DASH 1 CONSTRUCTION
DASH 2 CONSTRUCTION
WINDOW DETAIL : A
NACELLE TEST SECTION ASSY
6930-02-4511

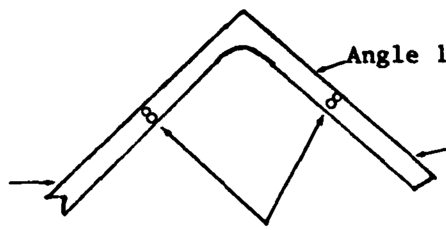
FIGURE II-4

Cross Section: 2 Radians; inner R. 15 inches
outer R. 24 inches

Length: 37 inches, flanged at each end (.625 thick) bolted to each other and to transitions.

Nominal Skin Thickness: .25 inches

Corner Construction: 4 Corners



Material: 321 Stainless Steel

Material Properties:

Tensile - Ultimate	(1000°F)	55,000	lb/in^2
(Short-Time Exposure)	(1500°F)	25,000	lb/in^2
Tensile - Yield	(1000°F)	34,000	lb/in^2
(Short-Time Exposure)	(1500°F)	15,000	lb/in^2
Young's Modulus - E	(1500°F)	approx 20×10^6	lb/in^2

Coefficient of Thermal exp. (32°-1200°F) 10.4×10^{-6} in/in°F

Change in arc length due to thermal exp.

15"R 0 to 1500°F - .468 inches

24"R 0 to 1000°F - .499 inches

Change in Chord on 15"R - .394 inches

Change in Chord on 24"R - .420 inches

Pressure Capability:

Buckling of 24"R due to altitude (3.5 psia) approx 35 psid
35/(14.7-3.5) = 3.1 (safety factor)

Buckling of 15"R due to Ram pressure (25 psia) approx
125 psid

125/(24-14.7) = 12 (safety factor)

Hoop Tension on 24"R 150 psid

Flange forces due to internal pressure:

Inlet and outlet transitions are attached to flow ducts by 24" dia. bolted flanges. The mean seal diameter of the flanges is nominally the same as expansion bellows; therefore, flange forces are independent of pressure and consist of only "bellows" rate forces and thermal stresses.

At three test section flanges:

Flange force = 143 P_{gage} + $F_{bellows}$

a. 25 psia, (P_{gage} = 10.3); F = 1473 + F_B (Compressive)

b. 3.5 psia, (P_{gage} = -11.2); F = -1602 + F_B (Tension)

Thermal Stresses:

Along 9" side wall - temperature gradient from 1500°F to 1000°F; skin will be in thermal stress of approximately 12,000 lb/in^2. During a heating cycle of the inner radius (0 to 1500°F) the area adjacent to the flanges will conduct radiated heat from the inner radius skin to the flanges. The rate of conduction from the radiation zone to the flange (approx. 2" adjacent to the flange) will act as a thermal choke, causing the flange to heat at a much slower rate than the inner skin. A significant thermal gradient will result in plastic yielding of the inner skin and an eventual fatiguing of the material in this area. The large thermal gradient can be minimized and thus the life of the sections increased proportionally if the rate of heating is reduced. Significant permanent distortion of the sections will occur prior to a fatigue failure.

The individual test sections are provided with mounting brackets attached to the flanges. These mounting brackets are fabricated from angles and are welded to the flanges. As indicated in the aforementioned analysis, there is a large thermal lag on the flanges, therefore, the mounting brackets will be relatively cool during heat-up and well into the test cycle. Each test section is supported on a horizontal set of support pipes by a pair of clamps at each of the four corners. The adjacent test sections are similarly supported. This permits removal of an individual test section, while leaving the adjacent test sections installed. Likewise, the radiant heaters are supported independently and a test section can be removed without disturbing the radiant heaters. During heat-up and cool-down, the clamps supporting the individual test sections permit differential thermal movement longitudinally along the support pipes. The collective longitudinal thermal movement is translated through the inlet duct to the expansion joint and could amount to as much as 2.5 inches. Thermal expansion of the nacelle test sections in the radial plane is absorbed in the form of deflection by the support pipes and the roll-over rings. The design of the roll-over support assembly was configured to provide the flexibility required in the horizontal radial plane while maintaining adequate vertical support for the nacelle test section.

The roll-over rings and support assembly are an integral part of a movable carriage. This carriage is constructed of a rigid, welded steel framework to which the roll-over rings and rolling gear is attached. The primary rolling gear consists of four rubberfaced wheels, two of which can swivel, which are mounted to permit movement in the longitudinal direction. This running gear will be used to move the complete engine nacelle assembly into, out of, and external to the hazard test area. After the complete assembly is brought into the hazard test area and positioned properly, a secondary set of (fixed) running gear will be lowered onto the existing steel rails in the hazard test area. The movable carriage and nacelle assembly is then pushed into the test position, final radial alignment of the inlet and outlet flanges is accomplished by individual adjustment of the secondary wheel jacks. Final longitudinal adjustment and fitting of the flange bolts is accomplished by adjusting the expansion joint tie-rods and insertion of an alignment spacer at the inlet flange. It may also be necessary to translate the carriage horizontally to the inlet due to its eccentric rotation. The spacer fits within the inside diameter of the flange bolts and is totally supported by them. The inside diameter of the spacer equals the 24-inch diameter inlet flange.

Visual observation into the nacelle test section is provided through two observation windows in each of the nacelle test sections, plus two in the unheated section. The windows are fabricated from 1/2 inch thick Corning Vycor glass which has good thermal shock resistance and adequate pressure capability at a reasonable price. The observation windows have been framed into a picture-frame type mount to minimize the probability of thermal distortion breaking the glass during the test cycles. Overstressing the glass during installation by overtightening one corner or edge is also eliminated with this approach.

The holding plate spacer contacts the metal picture frame coincident with contacting the glass, thereby insuring that a bending load cannot be transmitted into the glass. In addition, the gasket sealing material and resilient spacer material will cover both glass and metal frame to uniformly distribute the bolt loads. Stainless steel plates are provided to close off the window areas where the viewing capability is not required.

Access into the three test sections is provided by a nominal 12 inch by 12 inch port which is centered on the outside surface of the section. In addition, a similar access port is in the unheated inlet section. These access ports are normally closed with a welded cover assembly which provides a flush surface with the inside of the duct. An access cover with an 8-inch diameter Inconel rupture disc rated for 15 psig @ 1000°F (17 psig @ 72°F) is also available. This cover is interchangeable with any of the four ports.

Both the test section inlet and outlet transitions contain a 16-inch diameter Inconel rupture disc to prevent overpressurization of the nacelle test section. The disc was selected to provide relief at 15 psig at 1000°F (14 psig @ 72°F) for explosion relief venting. All three test sections also contain a 1-1/4 N.P.T. port for future installation of an ignitor. This port is currently sealed with a pipe plug. Each test section also contains two airstream thermocouples used for monitoring temperature variations throughout the nacelle sections. They are located approximately midway along the corresponding engine heating zone.

The inlet transition section contains two 1-inch sensor access ports which can be capped off, used for UV (fire) detection, or used for CO_2 injection. Another access port is also available for a vapor detector. All of these ports rotate with the nacelle test section.

The unheated nacelle section outer wall is tapped to provide access for thermocouples and a pressure tap. The thermocouples extend into the airstream to measure that air temperature while the pressure tap is flush with the inside surface to provide a static pressure indication. The outlet transition section also contains a port through which two thermocouples and a pressure tap are inserted. Again, the thermocouples extend into the airstream while the pressure tap is flush with the surface. Two sensor access ports are also available but have fixed locations. However, they are spaced such that at least one port is always open to view the test section. The lower view port is also fitted with a drain to prevent liquid building up in the viewport thus blocking the sensor. This section also contains four water quench nozzles which will be discussed later in detail. These quench nozzles can only be operated simultaneously with those in the exhaust system.

C. ENGINE/NACELLE HEATING

The Statement of Work called for the engine case temperature simulation to cover a minimum of 9 feet of nacelle length, with six controllable heat zones, and a capability to reach an engine side surface temperature of 1500°F. The heating system was also required to rotate 180 degrees with the nacelle test section.

A trade-off study was conducted and proposals were solicited covering five heating approaches as summarized in Table II-1. Two radiant heating proposals were received and evaluated. The panel approach using radiant infrared lamps, Figure II-5, was selected based on lower cost and an anticipated better and more uniform heating distribution.

Each of the nacelle test sections was divided to provide two independent yet identical heating zones. In this way, the requirement for six controllable heat zones along 9 feet of test section is met in full. Each heating zone contains thirty infrared lamps housed in five individual heating panels (Fostoria Industries Inc., Model 11712500-6). Each panel is capable of 15 kilowatts output due to direct radiation and reflected power off the gold plated rear surface.

Each panel contains integral water cooling and a clixon thermostat. The water manifold is adjusted for equal lengths through each heating panel. In this way each panel is assured of equal water flow of about 1 gpm. The clixon thermostats are used to prevent overheating the panel. The setting was established by the manufacturer and is not field adjustable. Cooling the heating panels is accomplished by using a closed loop distilled water system. Hot water from the heating panels is pumped by a Carver centrifugal pump at 35 gpm to a Young Radiator Co. heat exchanger, Model HF-806-AR-1P. This heat exchanger can transfer 999253 BTU/hour to cooling tower water which is flowing at the rate of 203 gpm. The distilled water is cooled to about 112°F. Air cooling of the lamp ends is provided by a 1086 cfm blower (M-2) whose flow is distributed equally to all three test sections.

Each test section also has its own air (FLS-3) and water (FLS-2) flow meters. The water flow meters are differential pressure sensors and are extremely sensitive since there is a minimal pressure drop through the heating panel. These flow meters are electrically connected in series to act like one flow meter. Loss of flow from any flow meter will terminate all radiant heating. Should system power be lost, a second circulating pump (ME-21) operating on the 24 VDC backup supply will continue to circulate the cooling water at 10 gpm until the water temperature is below 150°F.

TABLE II-1

ENGINE/NACELLE HEATING

APPROACHES

	METHOD	SIGNIFICANT ADVANTAGE	SIGNIFICANT DISADVANTAGE
1.	LIQUID MEDIUM	DIRECT CONTACT	COMPLEX/COST
2.	INDUCTION	----	COMPLEX
3.	COMBUSTION	COST	CONTROL/FLEXIBILITY
4.	RESISTANCE	SIMPLICITY	FLEXIBILITY
5.	RADIATION	FLEXIBILITY	COST MAINTENANCE

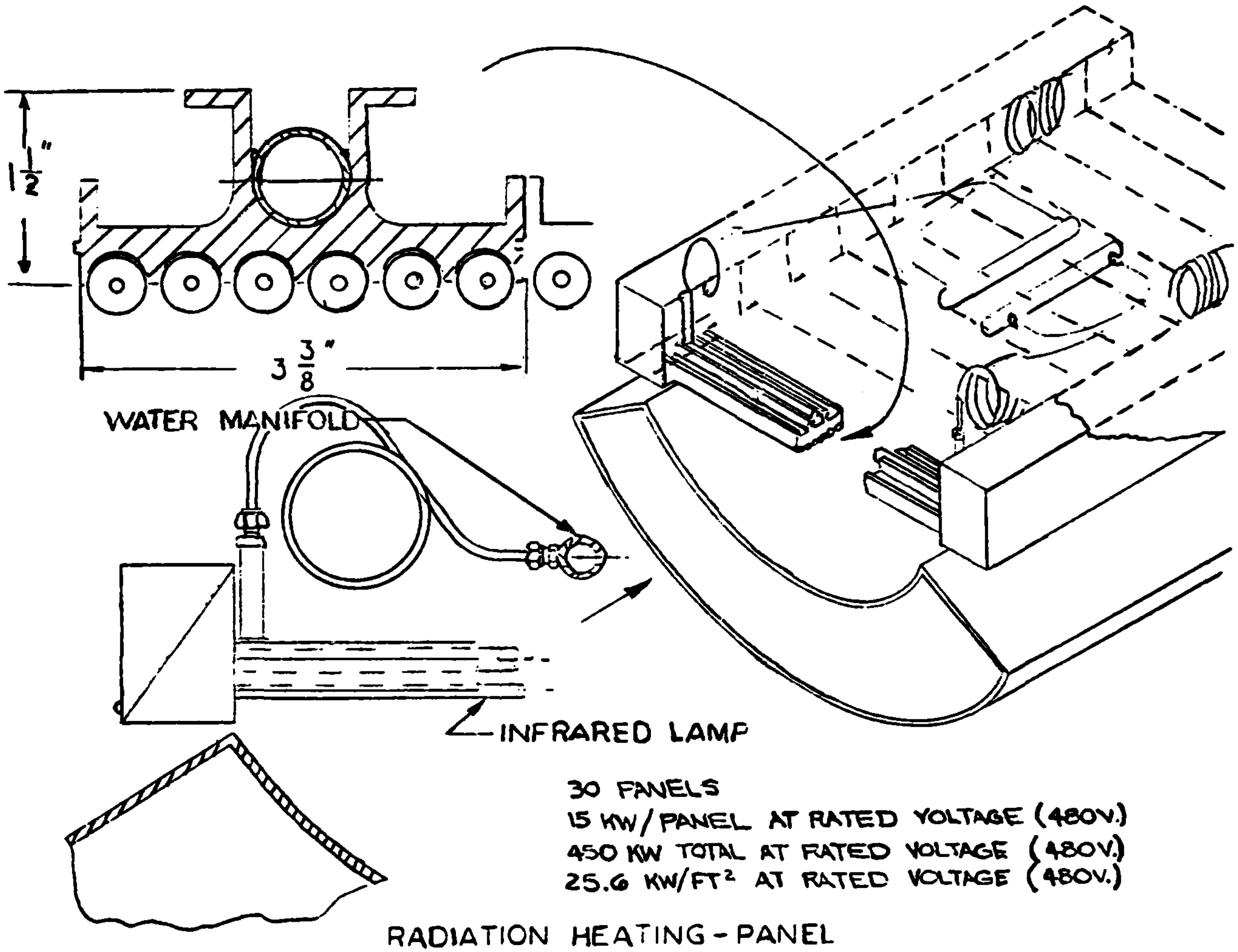

1 1/2"
3 3/8"
WATER MANIFOLD
INFRARED LAMP
30 PANELS
15 KW/PANEL AT RATED VOLTAGE (480V.)
450 KW TOTAL AT RATED VOLTAGE (480V.)
25.6 KW/FT² AT RATED VOLTAGE (480V.)
RADIATION HEATING - PANEL

Figure II-5

The infrared lamps are clear quartz infrared lamps, Type T3, Model F2548V, whose red ends are all on the same side of the heating panels. These lamps have limitations and will operate only when horizontal or in one vertical mode. The red end should not be raised more than 10° above horizontal when heating operation is anticipated. This does limit heating operation to about 200° of rotation and the test section should always be rolled toward the east wall. CAUTION, radiant heating is not possible when the nacelle test section is rolled away from the hazard cell wall. The design (rated) voltage of the lamps is 480 volts and the lamp life at this voltage exceeds 5000 hours. The lamp can be operated at other voltages (560 maximum), however, any higher voltage produces a corresponding reduction in lamp life.

The test sections are instrumented with thermocouples on both the inside (1) and outside walls of the engine skin and the nacelle outside skin. These thermocouples are used variously for readout, high limit controllers, and set point controller inputs.

D. AIR DELIVERY AND CONDITIONING

The Aircraft Engine Nacelle Fire Test Simulator is supplied with inlet air to duplicate test pressure conditions at atmospheric (sea level), above atmospheric (ram rise) and below atmospheric pressure (altitude). In addition, controllable heating and cooling of the air are provided. The inlet air supply originates from two sources: 1) an air blower with a minimum capacity of 8780 SCFM (11.2 pounds per second) and 2) a high pressure blowdown system, with a storage capacity of 8800 pounds of air at 2000 psig. The high pressure blowdown system is used to provide above atmospheric pressure (25.0 psia) and below atmospheric (3.5 psia) test conditions. An air ejector produces the low pressure test environment with the high pressure air system providing the primary air to operate the ejector.

1. Atmospheric System

The atmospheric air supply system has been tailored to fit into the I-Bay area. The blower has been positioned at the south end of the 28' x 40' room, directly south of the hazard test area where the nacelle simulator is located. A common centerline for the 24-inch diameter duct, approximately 5-1/2' above floor level, at a reference elevation of 819 feet, has been established for the blower outlet, the flow venturi, inlet heaters, nacelle simulator, and the exhaust outlet. A flow schematic of the atmospheric system is given in Figure II-6. The air inlet duct to the blower, and the blower bypass vent duct are directed to the roof directly overhead of the blower. The blower inlet duct is a 30-inch diameter duct where it penetrates the roof, and then transitions into a 18" x 36" rectangular cross section of equal area against the east wall of I-Bay. This permits the duct to pass behind the bridge crane and its supporting structure to the floor where it terminates in a 120 cubic foot plenum chamber. The blower is fitted with an inlet bell that extends into the plenum. The blower bypass vent is tied into the blower outlet, passes through a 12-inch diameter back pressure control valve (VP-1), and then through a 16-inch diameter duct which parallels the intake duct to the roof. Both the inlet and bypass vent ducts are topped with rain shields and bird screens, and are positioned to minimize recirculation of the vent air into the inlet. The maximum atmospheric blower flow through the nacelle test section is 16 pounds per second which is equivalent to 12800 SCFM. The Chicago Blower Corp., Model 4400 PA blower is rated at about 13800 SCFM at 1760 RPM and utilizes a 150 HP motor for rotational drive. Approximately 15 feet of 24-inch diameter ducting connects the atmospheric blower outlet to the flow control valve (VP-2). The flow control valve is used to provide airflow control. A venturi slides into the 24-inch diameter duct and is supported by the standard bolted pipe flanges sandwiching the venturi holding flange. The venturi is fabricated from fiberglass polyester type material, with an integral holding flange. The manufacturer estimates that the accuracy will be between 1 to 2 percent at rated flow. The BIF 0182-24-2931 Venturi is rated for ten pounds per second flow through a 10.158-inch throat diameter. At the maximum flow of 16 lbs/sec., the pressure differential across the nozzle is expected to be about 32 inches of H_2O.

ATMOSPHERIC PRESSURE SYSTEM

FLOW SCHEMATIC

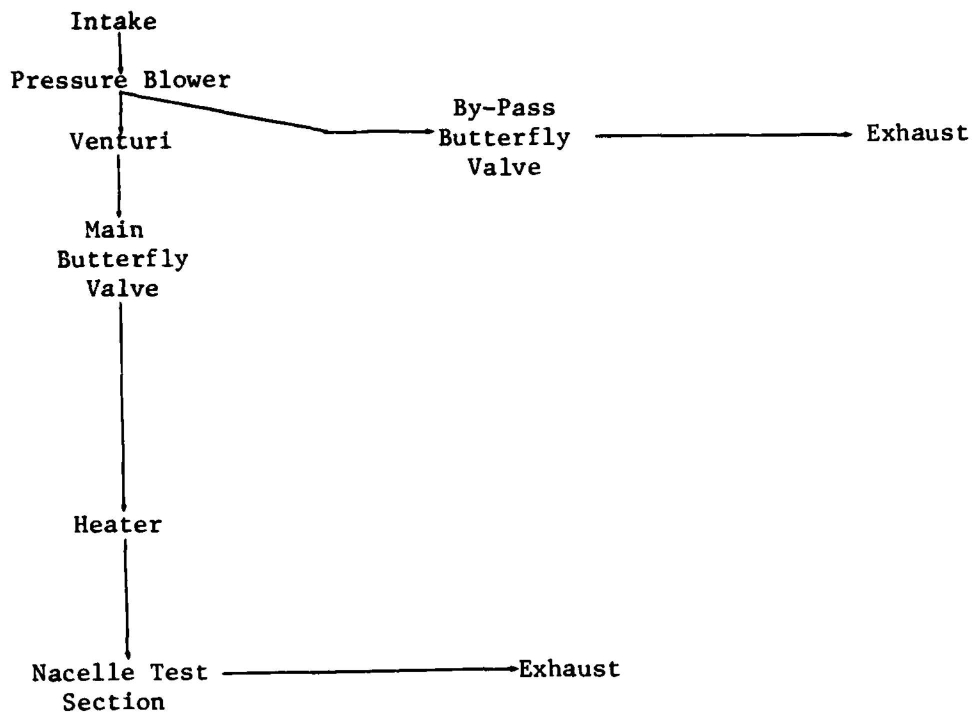
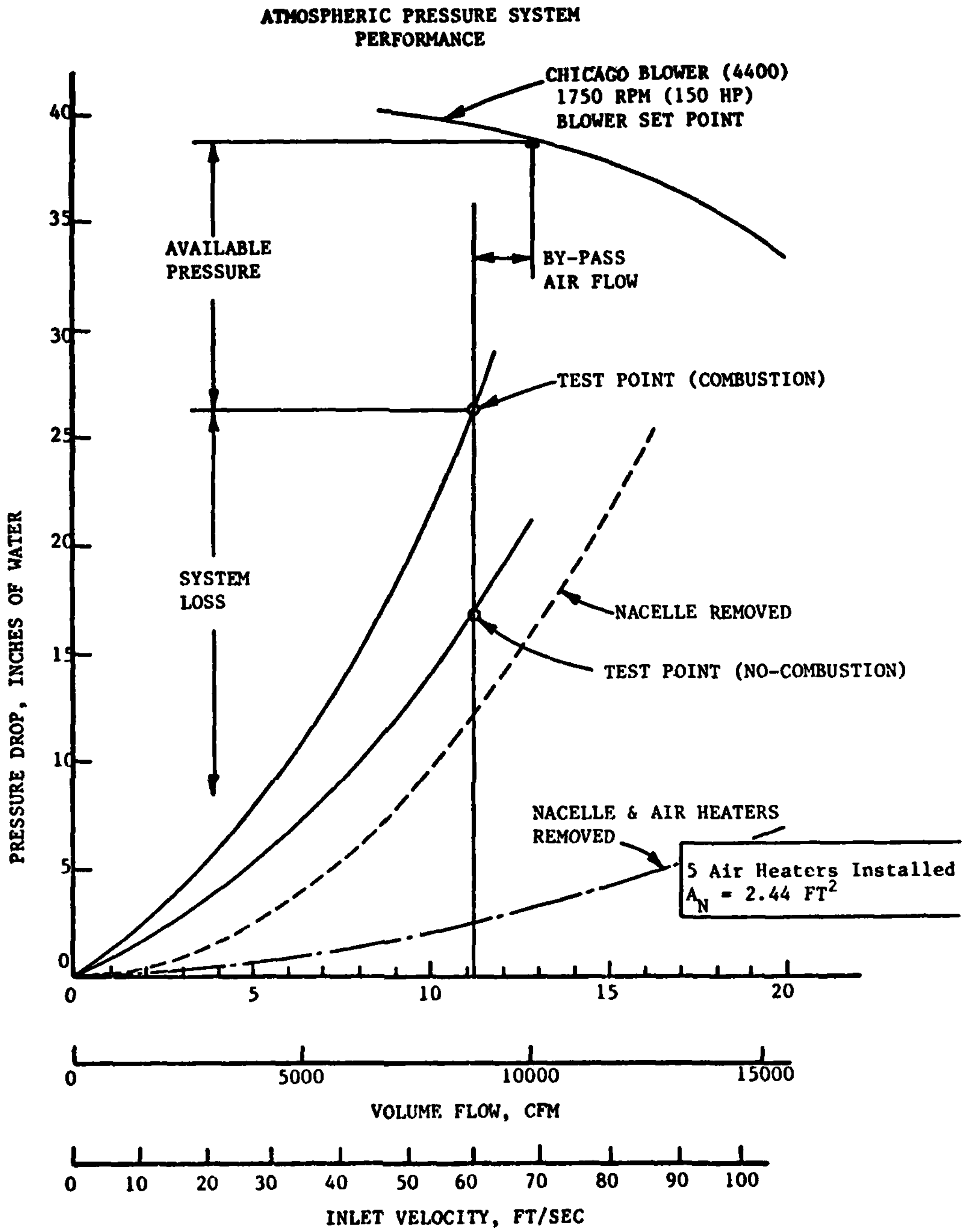


FIGURE II-6

The normal position of the 24-inch diameter flow control valve (VP-2) is closed and it opens only in response to commands from the set point controller. This valve is equipped with an elastomer lining on the valve body bore to provide a seal with less than one bubble per minute leakage in the closed position. This will insure against leakage of atmospheric air into the duct during 3.5 psia low pressure testing or leakage of 25 psia air to atmosphere during high pressure testing. Anticipated performance for the atmospheric blower system is presented in Figure II-7.

A flow control and back pressure vent system are used to control airflow to the engine nacelle test sections. Both systems utilize a pressurecurrent transmitter; a set point controller, a current-pneumatic transducer; and a butterfly valve with pneumatic actuator and positioner. The back pressure vent valve (VP-1) is 12-inches in diameter and is open whenever the system or atmospheric blower is off. This is also its position for a failure or emergency mode. This valve attempts to maintain a constant pressure drop (37 inches water) across the blower in order to keep its operation within the rated performance limits of the blower by venting excess air flow to the atmosphere. When flow is being controlled by the flow control valve, the bypass valve will close maintaining that same pressure. Lower flow rates (higher pressure) could cause the blower to become unstable (39 inches H_2O) while higher flow rates (lower pressure, 31 inches H_2O) will cause excessive power requirements on the blower motor. A small hand valve has been placed in the transducer sense line in order to slow the pressure fluctuations. As the flow control valve opens, the bypass valve will close to maintain blower performance and vice versa.

The expansion bellows is located next to the heater inlet transition and flow control valve. It provides up to 5.25-inches compression and 1.75 inches extension. A calculated 2.5-inches compression is required to accommodate maximum growth during hot testing. Under cold test conditions, the growth of the heated sections will normally more than off-set the contraction of the cold sections. Bellows extension under cold conditions is expected to total 0.5 inches. The 6-inch diameter blow-down system air supply duct enters the main 24-inch diameter duct upstream of the expansion



ATMOSPHERIC PRESSURE SYSTEM
PERFORMANCE
CHICAGO BLOWER (4400)
1750 RPM (150 HP)
BLOWER SET POINT
AVAILABLE
PRESSURE
BY-PASS
AIR FLOW
TEST POINT (COMBUSTION)
SYSTEM
LOSS
NACELLE REMOVED
TEST POINT (NO-COMBUSTION)
NACELLE & AIR HEATERS
REMOVED
5 Air Heaters Installed
A_N = 2.44 FT²
PRESSURE DROP, INCHES OF WATER
0
5
10
15
20
25
30
35
40
0
5
10
15
20
0
5000
10000
15000
VOLUME FLOW, CFM
0
10
20
30
40
50
60
70
80
90
100
INLET VELOCITY, FT/SEC

FIGURE II-7

joint. The air heaters (DH-1 to 5) are located in the same room with the blower, adjacent to the south wall of the hazard test area (immediately upstream of engine inlet). The total heating capability of 500KW is provided by five 100KW immersion-type heaters which fit into a rectangular duct area of approximately 21 inches by 27 inches and occupy approximately 6 feet of duct length.

Heating power is provided by five SCR controllers (PC-1 to 5) which control each heater independently but which have a common input. The output to each heater is continuously variable from 0 to 480 volts. The SCR units are located in the motor control center.

2. High and Low Pressure System

The high pressure (25 psia) and low pressure (3.5 psia) systems have a large degree of similarity, and therefore will be covered in a common discussion. Flow schematics of the two system are given in Figure II-8 and II-9. The high pressure storage (2000 psi) is made up of two tank assemblies, consisting of a cluster of eight tanks per assembly. Total volume of the two tank assemblies is 847 cubic feet. When pressurized to 2000 psi, they contain 8800 pounds of air. These air storage bottles were furnished as Government Furnished Equipment. They have a design pressure of 2800 psig, and a proof-test pressure of 4200 psig. The two tank assemblies were installed on an existing concrete pad approximately 30 feet south of I-Bay. The manifold outlets are tied together into a common 2-inch schedule 80 pipe, then routed to the southeast corner of I-Bay, brought down to ground level to pass under the doors, then vertical to an elevation of approximately 20 feet above the floor, northward along the east wall of I-Bay to the area of the atmospheric blower and duct heaters. This is a run of approximately 150 feet. The piping was welded in place and a proof pressure test to 3000 psig was performed to insure personnel safety.

The pipe running under the door has been flanged on its vertical runs to allow its removal. A condensate drain is located on the bottom of the piping to remove any effluent that collects there. A hand valve is

HIGH PRESSURE SYSTEM

FLOW SCHEMATIC

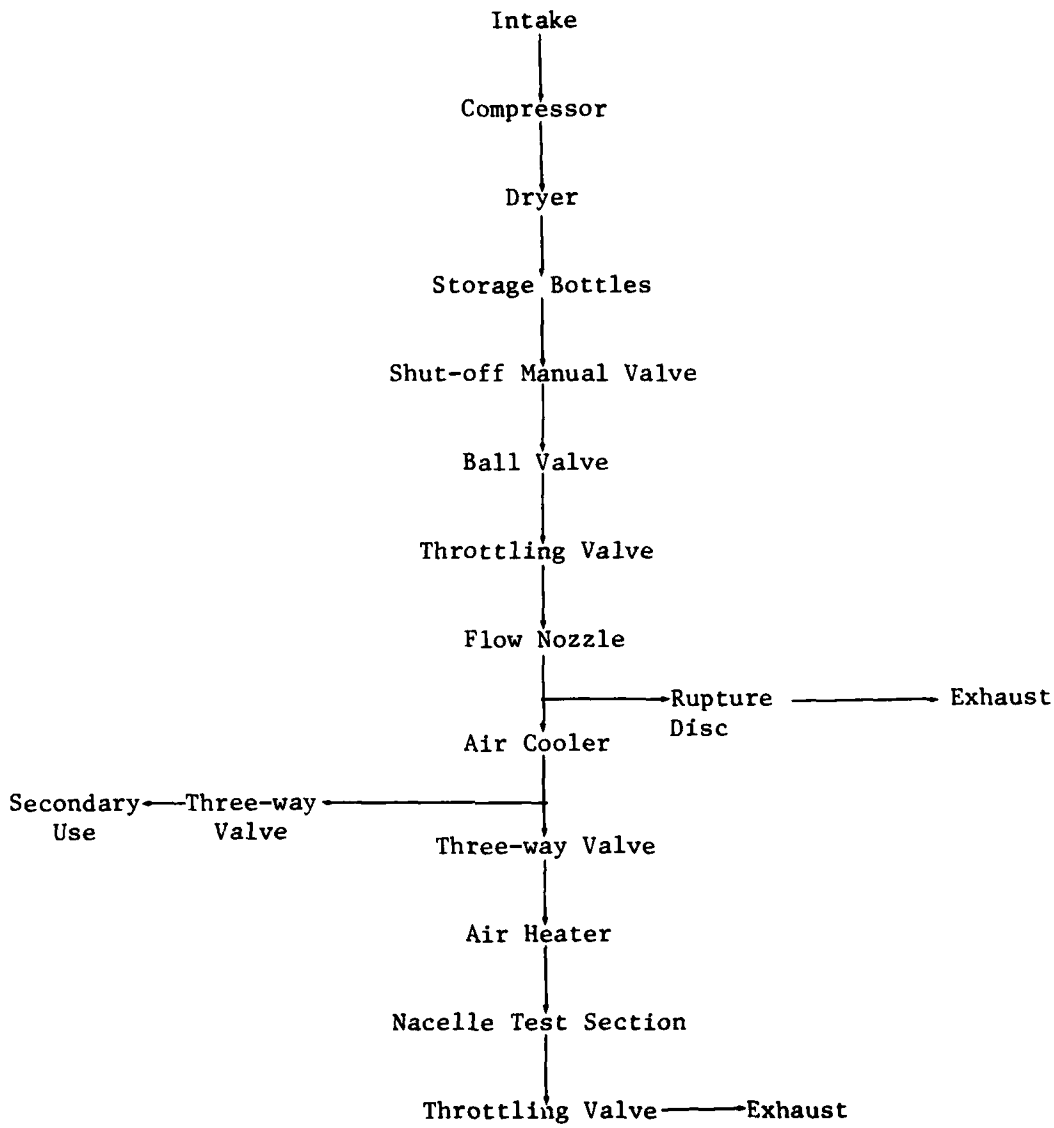


Figure II-8

LOW PRESSURE SYSTEM

FLOW SCHEMATIC

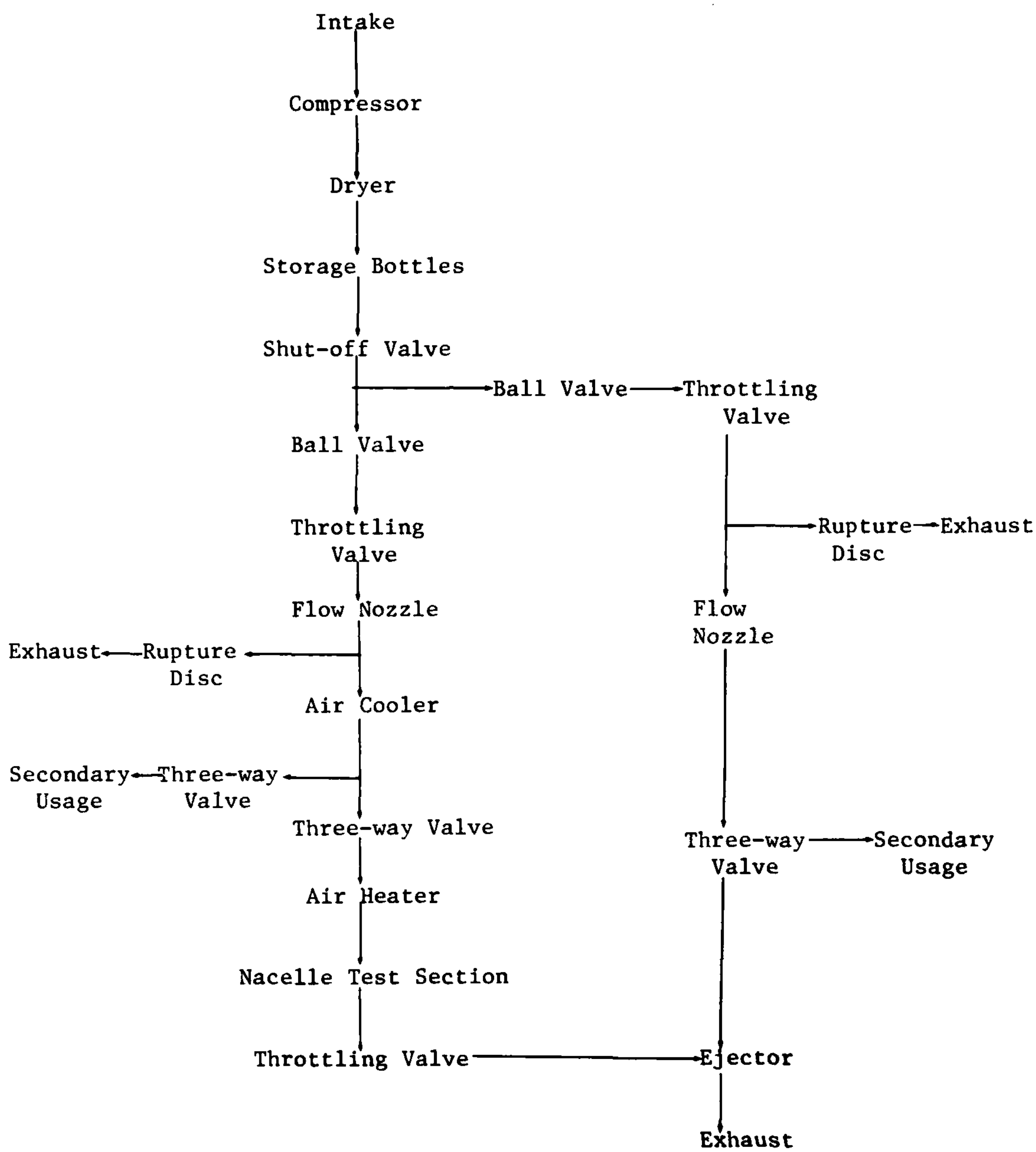


FIGURE II-9

located just above the inside flange to permit the bottle farm to be isolated from the rest of the high pressure system. The compressor, dryer, and oil removing equipment are located along the east wall of I-Bay. The compressor and dryer will deliver 100 ACFM of air (7.6 lb/min) at a dew point of +35°F at 2000 psig (-55°F at 14.7 psia and -76°F at 3.5 psia). The compressor and dryer have integral controls and pressure relief features which permit them to operate during the non-testing hours of the day. Immediately upon leaving the compressor, 2000 psig air flows into a modified 6000 psi high pressure cylinder (DOT-3AA6000 Nitrogen Cylinder) which has a two-fold purpose.

a. The bottle acts as a collector should the compressor fail thus preventing oil from being discharged into the down stream piping.

b. The bottle acts as a receiver tank to smooth out air pulsations from the compressor and allows smooth steady state airflow into the dryer and filters.

A drain system is incorporated with the cylinder to relieve any collected condensate or oil. The air bottle must be manually blown down periodically as experience dictates, to keep the insides dry. Otherwise internal oxidation will reduce the cylinder wall strength and could present a hazard.

The air then flows through a Ingersoll Rand Model 7 refrigeration dryer where the pressure dew point is lowered to +35°F at 2000 psig and from there into the oil and particle filters. Both oil and particle filters are rated for .9 micron nominal and serve to remove any oil or particulate matter that might result from the air compressor. Each filter is monitored with a pressure differential gauge to indicate when a filter should be changed.

After the filtration system, air then flows through the back pressure valve (1800 psi), a check valve, and into the air storage bottle farm.

When air flows to the nacelle it passes through a check valve just downstream from the compressor outlet. In this way, should any compressive detonation occur, the compressor and bottle farm are protected.

The high pressure air supply line terminates into two 2-inch diameter ball valve and a pressure regulator. These valves (SV-1 and 2) are solenoid-operated, pneumatically actuated shutoff valves, and are used to initiate high pressure or low pressure testing. The pressure regulator reduces the high pressure air to 100 psi which becomes the instrument air supply for the facility.

Downstream of the ball valve (SV-1), the high pressure line is again split into two branches; through one branch, the nacelle test airflow for high pressure testing is controlled, and through the second branch, the air for the low pressure testing is controlled. High pressure valves with pneumatic positioners that are controlled by a set point controller provide a selected pressure to the inlet of a fixed area flow nozzle. The flow nozzle is operated under choked flow conditions at all times; consequently, the mass flow rate of air through the nozzle is directly proportional to the nozzle inlet pressure. The flow nozzles are specifically designed for a choked flow application. Because of this characteristic, actual flow can be accurately controlled by modulating the pressure at the flow nozzle inlet. Available test time for various flow rates from the storage bottles is shown in Figure II-10. In the high pressure branch, the control valve (VP-5) and the flow nozzle are designed to flow from 1.55 lb/sec to 10 lb/sec airflow through a nozzle orifice area of 0.6740 square inches. At 1.55 lb/sec, the nozzle inlet pressure is 100 psia. The design rated flow for the high pressure system is 3.1 lb/sec, and at this flow condition, the nozzle inlet pressure will be 200 psia.

In the low pressure branch, the flow control valve (VP-6) and nozzle are designed to flow from 0.25 lb/sec to 1 lb/sec with a design rated flow of 0.43 lb/sec. The nozzle orifice has an area of 0.1082 square inches and the respective nozzle inlet pressures are 100 psia, 400 psia, and 172 psia.

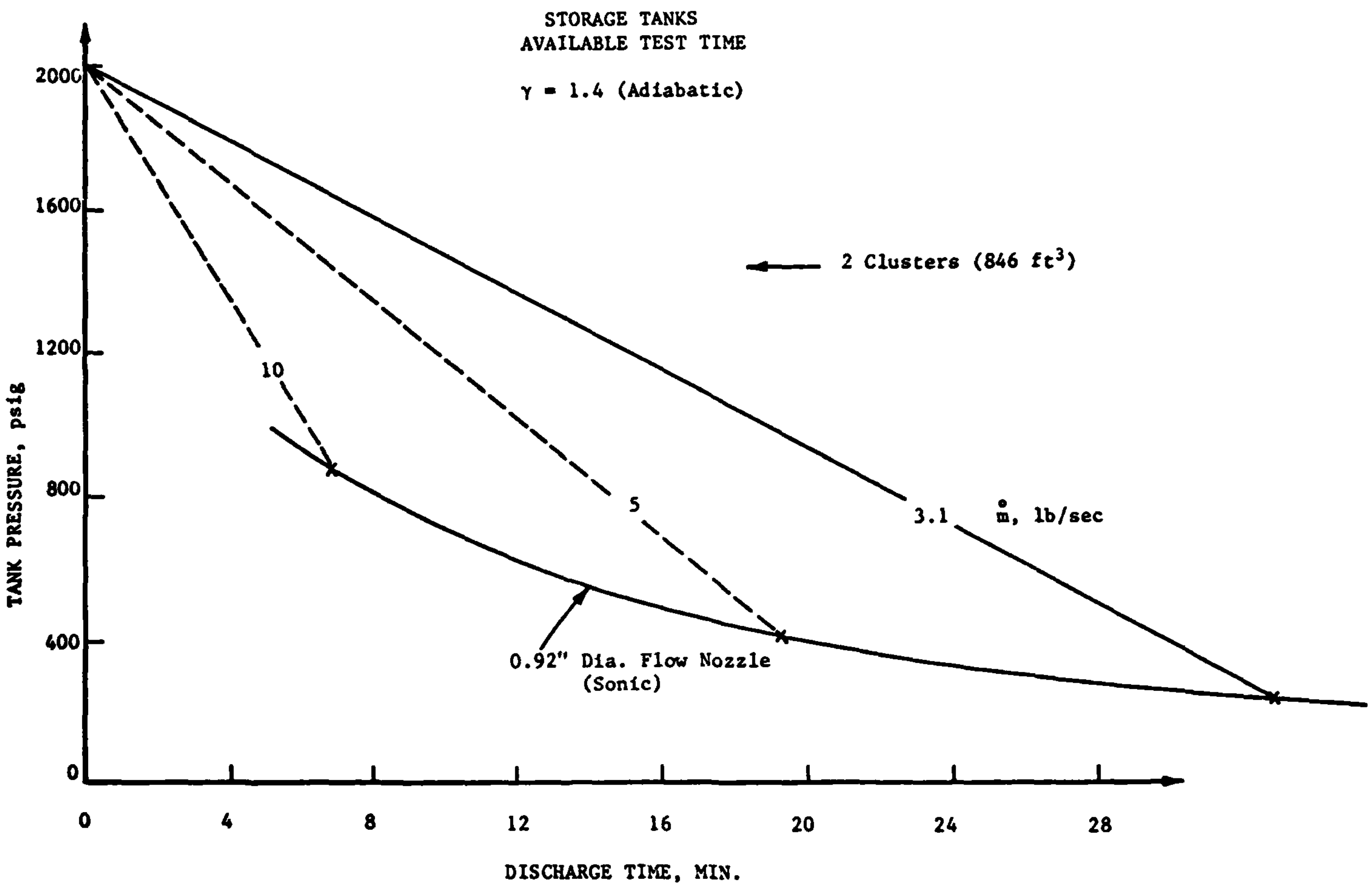

STORAGE TANKS
AVAILABLE TEST TIME
γ = 1.4 (Adiabatic)
2 Clusters (846 ft³)
10
5
3.1
ṁ, lb/sec
0.92" Dia. Flow Nozzle (Sonic)
TANK PRESSURE, psig
2000
1600
1200
800
400
0
0
4
8
12
16
20
24
28
DISCHARGE TIME, MIN.

FIGURE II-10

After the air passes through either the high or low pressure nozzle, it is then returned to a common line and passes through the Ethylene Glycol/Air Heat Exchanger and on into the main flow duct of the nacelle simulator. The heat exchanger was manufactured by Burlington Engineering Sales Company and is capable of transferring 4464 BTU/minute at the following conditions. The heat exchanger shell can handle 200 gpm with a 17.4 psi drop through the heat exchanger. Air flow from either the high or low pressure system is rated for 3.1 pounds per second through the heat exchanger tubes with only a 3.8 psi pressure drop. The heat exchanger can cool 3.1 lb/sec of air from 70°F to -30°F when the refrigeration unit with preconditioning of the glycol system is providing -35°F glycol to the heat exchanger.

For those tests requiring heated air, the air will pass through the Ethylene Glycol to air heat exchanger (no Ethylene Glycol flow) and be heated in the main duct heaters.

The second ball valve (SV-2) provides the air to the ejector for low pressure testing. The ejector performance is given in Figure II-11. The control concept is identical to the other control valve-flow nozzle combinations. The flow control valve (VP-7) can provide a design flow of 3.26 lb/sec at 100 psig to the ejector through a nozzle area of 0.5121 square inches.

The ejector should be operated at its design flow point and thus is capable of evacuating the nacelle test section to about 3.5 psia. During atmospheric blower tests, the exhaust area is kept unrestricted and bypasses the ejector to minimize the pressure head required of the blower. During high and low pressure testing, the blower flow control valve is closed to prevent air leakage. In addition, the exhaust area bypassing the ejector must be shut off.

Therefore, a 24-inch diameter exhaust valve (VP-3) is installed in the exhaust line so that the ejector inlet is upstream of this valve, and the ejector outlet is downstream of this valve. Additionally, a 10-inch diameter valve (VP-4) is installed at the ejector inlet. When operating

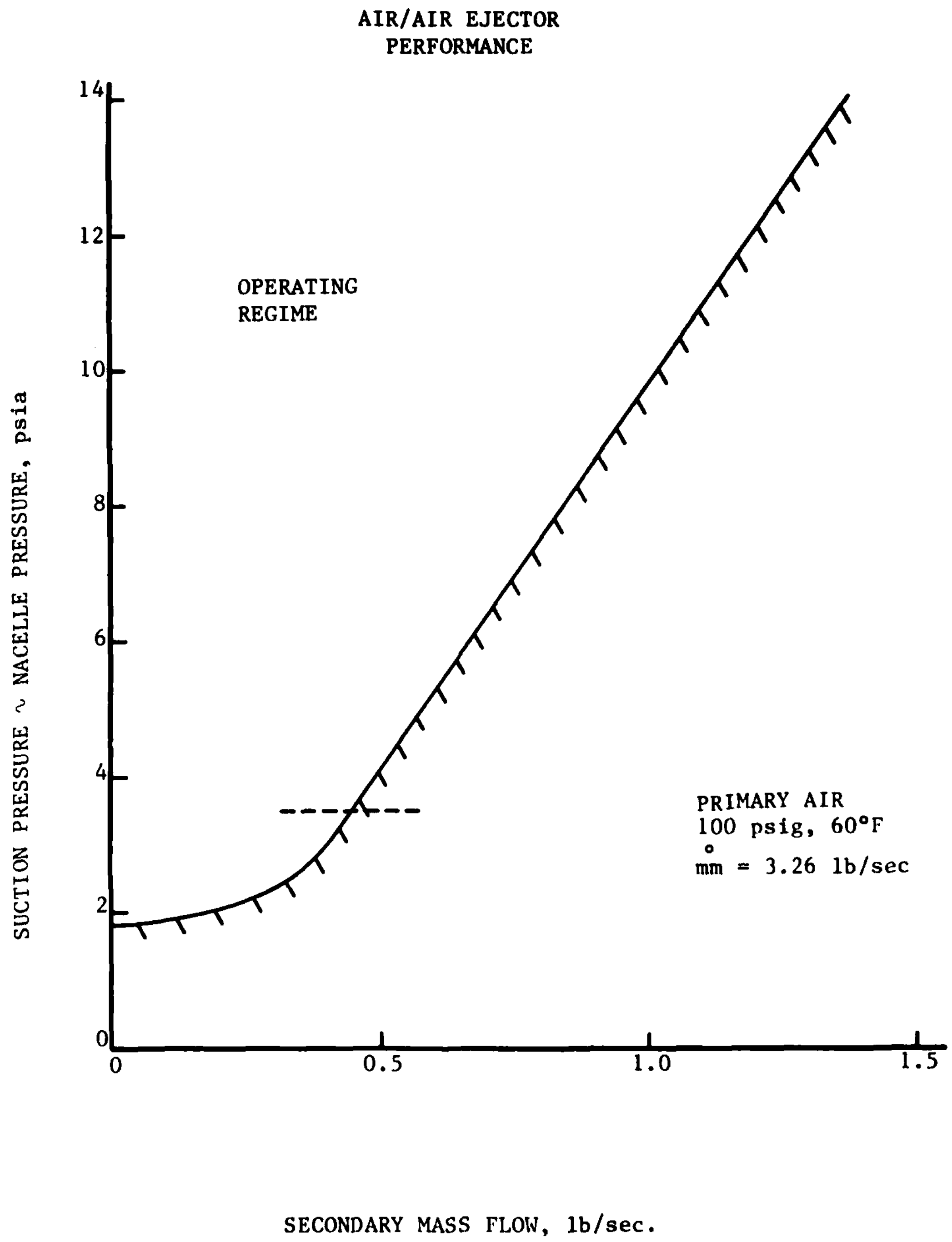

AIR/AIR EJECTOR
PERFORMANCE
14
12
10
8
6
4
2
0
OPERATING
REGIME
PRIMARY AIR
100 psig, 60°F
mm = 3.26 lb/sec
0
0.5
1.0
1.5
SUCTION PRESSURE ~ NACELLE PRESSURE, psia
SECONDARY MASS FLOW, lb/sec.

FIGURE II-11

at low pressure conditions (3.5 psia), the 24-inch valve (VP-3) will be closed, the air supply to the engine nacelle will be initiated by setting the low pressure flow controller and the ejector controller to the desired flow rate and opening both ball valves (SV-1&2), which provides nacelle test air and ejector air. The 10-inch valve (VP-4) at the ejector inlet is then throttled to set the exact nacelle pressure desired. Similarly, when a high pressure test is run, the 24-inch exhaust valve (VP-3) will be closed, the operator will set the high pressure flow controller to the desired airflow, open the one ball valve (SV-1) and again throttle the 10-inch diameter valve (VP-4) at the ejector inlet.

The ejector is inoperative during this test, but the 10-inch diameter flow valve is used to accurately throttle the exhaust to maintain the nacelle at the desired pressure level.

When the atmospheric blower system is used, the 24-inch exhaust valve will be fully opened and the 10-inch diameter ejector valve will be closed. These same positions are assumed during a power failure.

E. AIR EXHAUST

The air exhaust subsystem includes those components downstream of the nacelle transition, prior to exiting I-Bay at the north end. The major components include the 24-inch piping from the nacelle outlet to the 10- and 24-inch butterfly valves, the 10-inch butterfly valve (VP-4) at the ejector inlet, the 24-inch atmospheric throttling butterfly valve (VP-3), the ejector, the adaptive piping for the 10- and 24-inch pipe merging and enlarging to the 48-inch pipe, a water quench/sump section with rupture disc, an exhaust stack leading to the roof, a scrubber bypass valve (VP-9), the scrubber with recirculating water pump, scrubber-to-fan ducting (42-inch), and a centrifugal exhaust fan with outlet ducting. The majority of these components are made of 316 stainless steel to minimize corrosion and maintenance requirements and to provide the needed structural strength. A water storage system, called the separator, which is located at ground level at the north end of the building, accepts liquids pumped from the quench/sump section and also liquids which drain or overflow from the scrubber. In addition, hydrocarbons and contaminants are separated from the water by continuously skimming the water during a testing cycle. This sump water is pumped to the segregator tank located at the rear of the building where the fuel is removed and retained. Fresh water is provided to maintain the water level in the storage tank.

Twenty-Four-Inch Piping, Nacelle Outlet to Butterfly Valves

The selection of the 24-inch stainless steel pipe following the nacelle outlet was a compromise between the engineering requirements and practicality involving physical sizes, spatial relationships, and sequence of functions. The main function of this 24-inch piping is to handle the exhaust gas flow from the nacelle without serious pressure losses prior to the back pressure butterfly valving system. Of necessity, the 24-inch piping from the nacelle takes a height jog to clear an existing duct between its associated fan and exhaust stack. This jog also lengthens the piping between the north wall and the transition to the 48-inch pipe due to the fact that the ejector cannot be located in the jog area. A 16-inch diameter Inconel rupture disc is also located in this section. Its purpose is primarily to provide pressurization relief of the stainless steel pipe. The rupture disc is rated for 15 psig at 1000°F (14 psig @ 72°F).

Ten-Inch Butterfly Valve

The 10-inch Fisher butterfly valve (VP-4) was selected to match the 10-inch ejector inlet and primarily serves to control test pressures in the nacelle by creating a pressure drop at the ejector inlet. It alternately serves to block the ejector flow path when atmospheric air passes through the 24-inch throttling valve (VP-3). High pressure air is directed through the ejector (with no primary ejector air), and the 10-inch butterfly valve serves to control the back pressure in the nacelle. The valve is controlled by an electro-pneumatic transducer. The transducer input is a 4-20 mA current loop which generates a corresponding 3-15 psig control air signal. Using the 100 psi instrument air as the driving force, the 3-15 psig control air is translated into a linear movement which in turn controls the valve position. This valve is normally closed.

Ejector

A 10-inch Croll-Reynolds ejector was selected to provide the low pressure airflows in the nacelle. When supplied with 3.26 lb/sec of 100 psig primary air, the ejector will nominally handle 0.43 lb/sec of nacelle airflow at 3.44 psia against a back pressure of 12-inches of water in the exhaust duct. Increased flow rates can be handled at higher nacelle pressures (i.e., 1.0 lb/sec at 3.6 psia; 1.5 lb/sec at 14.0 psia; etc.), while decreased flow rates can be handled at lower nacelle pressures (i.e., 0.25 lb/sec at 2.2 psia).

Twenty-Four-Inch Atmospheric Throttling Butterfly Valve

The 24-inch Fisher butterfly valve (VP-3) was selected to be utilized in conjunction with the 10-inch ejector valve to permit flow through the 24-inch piping or alternately divert flow through the ejector. In the current operational mode, this valve is either fully open or fully closed. It does have a linear actuator which could be used to control the high pressure air flow back pressure. Its normal position is fully open and is closed only when high or low flow has been selected.

Adaptive Piping, 10- and 24-Inch Piping to 48-Inch Piping

The 10-inch piping from the ejector outlet was continued at the same elevation as the 24-inch piping downstream of the 24-inch butterfly valve. The ends of both the 10-inch and 24-inch piping sections are joined, utilizing 90-degree elbows, both directed in an eastwardly direction, with outlets of the 10-inch elbow intersecting the side of the 24-inch elbow. This piping arrangement turns the exhaust gas flow toward the east. This arrangement maintains a horizontal flow path in which quench/inerting can take place prior to turning upward into the 48-inch exhaust stack.

At the downstream side of the 24-inch, 90-degree elbow, a 24-inch to 48-inch transition section is located to reduce the air flow velocities and the pressure losses due to high mass flow rates associated with the possible simultaneous flows of 11.2 lb/sec air, 0.75 lb/sec combustibles, 14.5 lb/sec water, and 9.1 lb/sec extinguishant. This transition section is the initiation point of exhaust gas quenching/inerting.

Water Quench/Sump Section

Water quenching/inerting is initiated within the 24- to 48-inch transition section where 24 (two rows of 12) Spraying Systems Company Fogjet Hydraulic Atomizing Spray Nozzles, Number 1-7N14, yield approximately 15.6 lb/sec of water spray at about 340 psig. A 5-stage Carver centrifugal pump, Model WKL-50, is utilized to create a pressure head of about 340 psig for the nozzle flow. The nozzle set and pump combination were selected to provide the smallest practical water droplets in sufficient quantity (14.5 lb/sec) for evaporative cooling of the maximum heat load derived from the nacelle simulator. Each fogjet nozzle also contains a 1-QPW-50 Monel Strainer to prevent nozzle clogging. Spraying Systems Co. indicates a median volume diameter of 165 microns would be sprayed out of an LN14 nozzle at 350 psig. Each fogjet nozzle head, Number 1-7N14, has seven LN14 nozzles, and the flow rate through a single LN14 nozzle is approximately 40 gallons per hour at 340 psig. At 300 psig, 98 percent of the volume would contain droplet diameters less than 300 microns.

Utilizing the Bureau of Mines report, 7 January 1977, the equation for vaporizing droplets was utilized and reduced to the form:

$$R_o^2 = 0.00021106\ t_o$$

For R_o = radius of droplet in centimeters and t_o = evaporation time in seconds (see assumptions, calculations and graph in Volume III, Tab D of the FDR).

For droplets of 150 micron radius (as above), the evaporation would be accomplished in approximately 1.05 seconds. With an initial quench velocity of 109 ft/sec (corresponding to a nacelle velocity of 562 ft/sec) averaged with a pre-scrubber velocity of 43 ft/sec over the full 98 foot length of the 48-inch stainless steel exhaust duct to the scrubber inlet, a dwell time of 1.29 seconds is available. In addition approximately 8 percent additional water is provided to the quench nozzle for the maximum heat load anticipated, and the scrubber provides additional sprayed water for evaporative cooling during the scrubbing process. Therefore, sufficient evaporative cooling is available for the maximum heat load produced by 11.2 lb/sec airflow with 0.75 lb/sec of fuel burned utilizing 15.6 lb/sec of water. Caution must be observed in the operation and maintenance of the water quench system to prevent degradation of the quench system performance. Although safety interlocks exist within the control system, not all parameters can be controlled which could lead to thermal degradation of the fiberglass scrubber and fan material.

The water spray in the 24-inch to 48-inch transition section also functions to inert combustible mixtures in the exhaust stack. Extrapolation of Bureau of Mines data (7 January 1977 Report, Figure 5) indicates that 25 x 10^{-3} $\ell/min/cm^2$ of 20°C water utilizing droplets of less than 300 microns in diameter are required to inert a 9.1 percent methane air mixture. This translates to a 55.16 gal/min water spray for a 48-inch diameter duct. The pump and nozzle set utilized in this design deliver 112.16 gal/min to the 24-inch to 48-inch pipe transition section. Therefore, sufficient water spray volume flux is available to avoid flame propagations of combustible mixtures in the exhaust stack due to ignition delays in the nacelle test section. An additional array of four 1-7N14 quench nozzles is immediately downstream of the nacelle in the nacelle outlet transition section. They provide some immediate quenching of gases leaving the nacelle test sections. These nozzles are connected in parallel with the main nozzles and can be turned on only when the quench pump is on. They can however be manually turned off independent of the main nozzles. Their use should be limited when using the low pressure/ejector system. These nozzles require about 18.6 gpm at 340 psig. The Carver pump is rated to carry the full load of all the nozzles.

The water spray is initiated either when heated exhaust air is above 190°F or prior to fuel injection. In addition, the water spray is continued until the airflow system is in a safe condition. Much of the time, therefore, the water sprayed into the exhaust system is not entirely evaporated. To avoid water buildup in the pipe at the nozzle spray area, a 24-inch diameter sump was installed for the horizontal 45-degree elbow (48-inch diameter) which is downstream of the 24-inch to 48-inch adapter section. This sump serves to collect unevaporated nozzle water and additionally serves to collect potential liquid combustibles which are not vaporized in the nacelle test section. The sump is equipped with a float-level switch (FL-3) and an outlet connection to a Carver centrifugal pump/motor combination (M-20) which can deliver 130 gal/min at 16 psig. The accumulated liquids are pumped from the sump to the water separator tank when the level reaches the float switch.

Exhaust Stack

The exhaust stack consists of all the 48-inch stainless steel piping between the quench/sump section and the fiberglass scrubber. This piping serves two equally critical functions: 1) minimizing the accumulated pressure losses while handling the accumulated flow of the combustion products, the evaporated and/or free water results from the quench process and the extinguishant, and 2) practical maximization of the flow volume (flow area times pipe length) to provide adequate dwell time to assure evaporation of the quench water droplets.

Initial calculations based on the required calculations were performed for the atmospheric system, i.e., 11.2 lb/sec air, 0.75 lb/sec fuel burning, 14.5 lb/sec water, utilizing a 48-inch diameter exhaust stack. The pressure drop through the entire atmospheric system was found to be less than 29 inches H_2O. The time available to complete the evaporation of 14.5 lb/sec of water as mentioned earlier, in the Quench/Sump discussion, was calculated to be 1.29 seconds, and evaporation was calculated to be complete in 1.05 seconds. It is emphasized that the above numerical discussion applies to the most extreme conditions anticipated for tests conducted utilizing the atmospheric air delivery system. Further, the most severe conditions attained from the atmospheric air delivery system, with burning, are far in excess of the conditions in either the high-pressure (25 psia) or low-pressure (3.5 psia) system, basically due to the relative magnitude of the maximum mass flow rates, i.e., 11.2 lb/sec for atmospheric flow, 3.1 lb/sec for high pressure, and 1.0 lb/sec low pressure flow.

The volume flow rate at the end of the quench process 32,773 cfm, was determined from the mass flow rates of saturated steam (combustion products and water), the 192°F saturation temperature, and the average molecular weight at atmospheric pressure. On this basis the scrubber and fan were selected.

Due to the size of the piping selected, the portion of the exhaust stack from the ground level to the expansion joint at roof level weighs approximately four tons. The existing concrete pad had no footer, therefore provisions were made for another concrete pad east of the existing one. This location was selected for two reasons: 1) the vertical stack would be close to an existing building beam for tie-in, and 2) the location of the pipe at roof level provided the most direct path to the scrubber location over the structural wall between I-Bay and J-Bay.

The 48-inch piping between the expansion joint at the roof and the scrubber consists of a short, straight section, a 48-inch tee, a straight section over the existing door recess structure, a 60-degree elbow turning downward to the scrubber, a straight section angling toward the scrubber, another 60-degree elbow to align the flow path to the inlet, and a transition section to adapt the 48-inch pipe to a 54-inch wide by 36-inch high rectangular scrubber inlet.

The tee on top of the 48-inch straight pipe contains a double hinged butterfly valve which has been provided to perform a pressure relief function. The butterfly valve will swing open vertically when the pressure differential exceeds 2-inches of water. When the scrubber system is not required this valve can be manually opened from the ground and the exhaust, then bypasses the scrubber.

A 24-inch rupture disc is located just past the quench nozzles prior to the duct turning to go up the building. This rupture disc prevents any overpressurization of the 48-inch duct and also protects the fiberglass scrubber and ducting. This 316 stainless steel rupture disc is rated for 2 psig @ 300°F (2.3 psig @ 72°F).

Bypass Valve

The bypass valve (VP-9) is located in the short, straight section over the I-Bay doors at roof level and serves to bypass the scrubber and exhaust fan when the upper airstack temperature is less than approximately 160°F (with no fuel burning). In addition it provides make-up air, if necessary, to maintain the required airflow through the exhaust fan when the scrubber and fan are being operated.

Scrubber

The Ceilcote Co., Inc., SPT-544 modified scrubber, was selected for use in the air pollution control system. The scrubber is a packed bed scrubber and is constructed of fiberglass reinforced plastic (FRP) to avoid potential corrosion problems from the extinguishants, i.e., chloride, fluorides, and bromides, etc. The main purpose of the scrubber is to remove these soluble chemicals from the exhaust gases by absorbing them into the recirculating water.

By necessity, the scrubber must be able to receive the flow from the exhaust stack (32,773 cfm) and handle that flow with minimal pressure losses which could affect the nacelle performance. Nominally, the SPT-544 is a 33,000 cfm scrubber.

Theoretical sizing calculations, based on a previous Systems Technology Inc. report, were made for the scrubber. The results indicated the minimum requirements were a packed bed of 1.63 feet, using a 90 percent efficiency, a water flow rate of 327 gpm, and a diameter of 5.27 feet. The installed SPT-554 scrubber has a packed bed of 4 feet, requires water flow at 387 gpm and has a diameter of 9 feet.

Other features include a demister pad to remove free water, a 9 KW heater for freeze protection, manholes for maintenance, water spray nozzles for bed scrubbing and cooling, and a water reservoir collection sump. The water spray nozzles require 387 gpm which is provided by a closed loop centrifugal pump.

A Carver centrifugal pump and 7-1/2 HP motor (M-18) provide recirculation of the water from the sump to the spray nozzles.

The scrubber is plumbed with a make-up water line from I-Bay and an overflow/drain line to the water separator tank (routed through the building). Complete draining of the scrubber is accomplished by a hand valve located at the scrubber. For safety, the overflow outlet has no valve between the scrubber and the separator tank.

The scrubber is equipped with a float level switch (FL-1) to open or close the make-up water valve (SV-14) located in the building, a thermostat to operate the 4.5 KW heaters, a water line heating tape, and a pH sensor for monitoring water quality. The basic technique for freeze protection is to avoid stagnant, filled lines from being exposed to cold outside weather conditions and, as necessary, to heat those water flow paths which are exposed. The fill line is drained by using a 3-way solenoid operated valve. When energized the valve permits water to fill the tank until the float switch is actuated. When the valve is deenergized, the water above the valve is automatically drained into the scrubber overflow line. The water reservoir is heated using two 4.5 KW immersion type heaters (WH-4&5) which are thermostatically controlled by the outside air temperature (T-44). 110 VAC heat tape under the insulation on the scrubber pump (M-18) and the nozzle supply lines are also thermostatically controlled.

Scrubber-to-Fan Ducting

The scrubber is a vertical-standing unit, approximately 17 feet tall with a 42-inch diameter outlet. Three 42-inch elbows and two sections of 42-inch FRP were selected to join the scrubber and fan. The fan also has a 42-inch diameter for its inlet.

Exhaust Fan

A FRP Celicote centrifugal fan, model CMHP-42, with a 100 BHP motor (M-16) was selected to induce a negative pressure differential in the exhaust duct. The fan is capable of providing 33000 SCFM at 9 inches of water pressure at sea level and 70°F. When the exhaust fan is operating, the bypass valve (VP-9) is used to maintain the scrubber static pressure at 9-inches H_2O below ambient. This assures that all flow is through the scrubber.

Roof Platform

A roof platform was designed to support the load of the scrubber (12,800 Lb) and its 0.5-inch deck plating, the fan, the recirculating pump, and the ducting between the scrubber and the fan. Since the roof loading could have been a problem in the center of the roof, the platform was designed to distribute the load over the area at the loadbearing structural wall between I-Bay and J-Bay. The average roof loading is well below 100lb/ft^2.

Water Treatment System

A water treatment separator tank has been provided at ground level at the north end of the building, adjacent to and physically connected with other equipment at that location. The tank serves as 1) a reservoir for quench water pumped through the nozzles, 2) a fuel/water separator for liquids returned from the quench/sump area, for overflow from the scrubber, and for water drained from the scrubber make-up waterline, 3) a vessel where the pH of the water can be measured, and 4) a collection point for all liquids prior to being pumped to the facility waste fuel segregator.

The tank has been custom constructed of FRP by Beetle Plastics, Inc. and includes a top to contain splash due to fill and return liquid agitation. The tank fill and drain lines are in the bottom of the tank and run to the inside of I-bay through hoses which are contained in a tiled trench in the concrete pad.

A water fill line (make-up water) comes from a 1-1/2-inch base waterline and is directed into the bottom of the tank. This water fill line is controlled by a solenoid value (SV-15) in I-Bay. Inside the tank, 1-1/2-inch PVC pipe directs the make-up water flow to the quench pump inlet. If the quench pump (M-17) is not operating the flow will backwash the quench inlet screen and fill the tank until the float switch is reached.

The scrubber overflow is also plumbed directly into the bottom of the tank and is simply a gravity feed. The separator overflow also discharges through the bottom of the tank. A 1-inch diameter hole has been cut in the bottom of the overflow stand pipe to ensure a continuous water supply for the sump pump (M-19). This is also the drain through which the tank is emptied. Should the sump pump fail as determined by the pressure switch, FLS-8, any further filling or quenching will be terminated.

A pH monitor is utilized in the separator tank to monitor and evaluate the system's water quality. Freeze protection is provided throughout the system. The separator tank contains two 6 KW heaters (WH-1&2), each with an integral thermostat (T-46&47) for overheat protection, which are activated when the outside air temperature drops below 40°F as sensed by T-43. All external quench lines, the exhaust sump, and the sump drain lines have been protected with heat tape and insulated. The heat tape is also activated at low temperatures. The quench line running inside the building to the four nacelle exit nozzles are only insulated. Therefore that line must be drained after each test during conditions of cold outside temperatures. Heat tape has also been placed in the conduit surrounding the tile trench which leads from the separator pit to the I-bay interior. This tape is thermostatically activated by T-45.

The separator sump pump (M-19) is capable of pumping 50 gpm at 30 psig to the segregator. As mentioned previously, the nacelle outlet transition also contains a sump pump to prevent the accumulation of fluids which may backwash into the test section or plug the lower view port. This pump is an air operated Sandpiper ST1-A. The pump is rated at 16 gpm at 15 psig and is routed into the facility segregator. The pump is activated any time the pollution control equipment is on by SV-17 which turns on the instrument air supply to the pump.

The fluid dispensing system also is routed into the segregator tank. The motivating force however, is the nitrogen head on the fluid dispensing system. Each of the three segregator dump systems is isolated from one another through check valves.

F. AUXILIARY EQUIPMENT

1. Combustible Fluid Injection

The simulator includes a subsystem capable of injecting combustible fluids into the test section. It can be used for generation of fires or for investigation of hot surface ignition. Fluids of interest include:

a. Jet fuels up to 500°F and 400 psig with a 5 gallon supply and a dispensing flow rate of 0.75 lb/sec (6.75 gpm).

b. Hydraulic fluids up to 300°F and 4000 psig with a 2 gallon supply and a dispensing flow rate of 0.75 lb/min (0.1 gpm).

c. Engine lube oils up to 500°F and 200 psig with a 2 gallon supply and a dispensing flow of 0.75 lb/min (0.1 gpm).

A dual pressurized tank injection system was implemented. This concept was found to be the most advantageous from a performance, flexibility, safety, maintenance, and cost standpoint. One tank (2 gallon) is used primarily to contain and condition 4000 psig hydraulic fluid, while the other tank (5 gallon) is used to contain and condition the higher temperature fuel.

The combustible fluid dispensing system is totally contained on a castered equipment pallet assembly. This permits the equipment to be used in the hazard test area where the injection lines can be as short as possible, and insures that fluids at the desired temperature and pressure level are readily available at the point of injection. The hot fluids present a definite personnel hazard; therefore, it is desirable to have it located in the hazard test area where protection is available. Servicing of the injection system should be accomplished before the beginning of a test and the system put on a stand-by basis until required during that test.

The hydraulic tank utilizes component parts of a high pressure hydraulic cylinder; two end caps, a cylinder, and tie rods. This cylinder has a nominal service rating of 5000 psig; with a stress to yield point in excess of 8000 psig. The capacity of the tank is 2.2 gallons. Operational temperatures can go up to 500°F.

The fuel tank was fabricated from standard 30304 schedule 40 stainless steel pipe and piping accessories. The finished tank has a capacity of 6 gallons and a pressure capability of 400 psig at 500°F.

One high pressure nitrogen (6000 psig) and one 2000 psig bottle are provided to pressurize the tanks. These bottles are commercially available. The high pressure bottle will be used from 6000 to 4000 psig as a supply for the hydraulic tank (4000 psig). It can then be changed over, and used as a supply for the fuel tank from 4000 to 400 psig if needed. The 2000 psig bottle is normally to be used on the fuel side.

The nitrogen supply system to each fluid tank is totally independent of the other fluid tank and each system contains a relief valve to prevent accidental overpressurization of that particular tank. These valves are set at 400 and 4200 psig, respectively. A separate regulator operating off the fuel pressurization system is provided to supply the 100 psig gas required to operate the injection valves and diverting valves. Therefore to operate either side of the cart the fuel system must always be pressurized.

Heating of the tanks is done by using nine band heaters on the fuel tank, and twelve strip heaters spaced between the tie bolts on the hydraulic tank. The heater control for each tank consists of dual temperature controls, one sensing the container temperature and the other sensing fluid temperature. The heaters are wired in series and permit heating as fast as possible without producing local hot-spots on the fluid tank surface. When the set temperature is reached, that temperature will be automatically maintained. Depressing the red knob on the control box on either side of the cart will terminate all further heating until the system is reset in the control room. The only nonmetallic materials in either injection system are the ball valve seating material which is Teflon, the gasket on the fuel tank which is asbestos, and the seals in the hydraulic tank which are Teflon. This provides the maximum possible amount of sealing capabilities for fluids likely to be used in the injection system. Neither tank is specifically dedicated to a particular fluid. Primarily, it is recommended that fluids use the stainless steel tank for pressures below 400 psig and for temperatures to 500°F. For pressures above 400 psig, use the hydraulic tank, however this tank is limited to 300°F at high pressures. Caution should be exercised if a particularly corrosive fluid is selected for injection.

Injection nozzles should be precalibrated with the fluid at the pressure and temperature to be used for that particular test. The injection flow rate can then be established by the proper pressure setting on the nitrogen gas regulators. The regulator flow capacity is sufficient to maintain a constant pressure in the tank.

Each fluid injection system contains four solenoid valves and one manual drain valve. Caution must be exercised when using the manual drain if there is pressure on the system. In normal operation only one tank should be exercised at a time. The corresponding dump line should be connected with the quick disconnect to the segregator dump line. The injection line is then connected to the corresponding test section port. The injection line contains two solenoid valves (i.e., SV-8&10 for the low pressure side) and both valves must open to allow any fluid injection. The dump valve is tied together with another solenoid valve in the nitrogen pressurization line. When the dump valve is opened, the nitrogen valve is closed. This prevents high pressure nitrogen from damaging downstream components. Each tank also contains a pressure transducer to provide remote display of the internal pressures. During a fluid dump, a decrease in pressure to near ambient indicates completion of that dump cycle. Note--when operating the high pressure system, the low pressure fuel side must be empty. Since the fuel side must be pressurized for all operations, an emergency dump activates both sides of the fuel cart. Since there is only one dump connection, anything left in the other tank will be dumped around the general area.

2. Fire Control and Extinguishing

The Nacelle hazard test cell has three independent CO_2 deluge modes. These are: Test Cell Flood; Fluid Card Spurt; and Nacelle Spurt. The test cell flood can be activated from the floor of I-Bay, on the wall of the control room, or from the control console via S62. Initiating this sequence will stop the test cell ventilation system and initiate a preset timed dump from all four discharge horns located in the four corners of the test cell. This dump is capable of about 2000 pounds per minute.

The fluid cart spurt is a momentary action pushbutton, S-63, which dumps CO_2 over the top of the fluid cart as long as the switch is depressed. This spurt mode is capable of about 73 pounds per minute. Both of these systems utilize a J-Bay CO_2 source, are powered by 110 VAC facility power, will activate an alarm horn, and will automatically notify the fire department of an emergency.

The nacelle spurt can be initiated from the control console via S61 or from the control room wall. This dump is also momentary and utilizes a CO_2 source on the north pad of I-Bay. As long as the switch is maintained, CO_2 will be injected into the nacelle test section inlet and outlet at a rate of about 600 pounds per minute. If instrumentation is utilizing the sensor ports the appropriate line valves must be closed, however at least one line must be connected at all times. This circuit operates off the 24 VDC backup battery power supply.

G. TEST FACILITY INTERFACES

The primary site interfaces consist of the internal and external building modifications for the installation of the test and support equipment, the electric power distribution system, the refrigeration system, and the tie-in and routing of water lines and instrument air systems.

Internal modifications to the building include a concrete pad for the atmospheric blower and motor. This pad was required both to raise the motor and blower to the height necessary to fit the nacelle inlet ducts and to provide additional support and mounting for the weight of the equipment. Two trenches were cut in the existing flooring to set the necessary tie rods. Concrete with a minimum 28 day strength of 3000 lbs per square inch was then used to pour the new pad. Penetrations of the roof were also necessary to accommodate the atmospheric blower inlet and bypass ducts. Thirty- and sixteen-inch penetrations were made through the roof and ceiling slab. The roof holes were later sealed with flashing. The stairs which provided access to the upper level of the hazard facility were also moved to provide an unobstructed penetration in the south wall for the nacelle air intake ducting. The second floor door leading to the hazard cell has been sealed.

External modifications included a new pad for the transformer and the expansion of the north pad and a mounting platform for the pollution control system. The transformer pad was modified to accommodate the sizing an weight of the transformer. A reinforced concrete pad was implemented.

The north pad was expanded considerably to accommodate the new equipment. The north pad was poured to support about four tons of vertical exhaust stack, the CO_2 storage tank, the separator tank and pit, and the water line trench. All new concrete was reinforced with a 6-inch by 6-inch steel mesh and had a minimum 28-day strength of 3000 psi. A portion of the area beneath the separator contains a work pit with a manhole and cover for access. The mounting platform for the pollution control equipment was centered on the roof between I-Bay and J-Bay. All standoffs were made of

6-inch schedule 40 pipe and were located over the existing roof support structure. A framework of 6-inch by 6-inch H beams was layed across the standoffs and then covered with a 1/2-inch thick steel plate. This structure supports a total of about 25000 pounds on a total of twenty pads of about 78 square inches each. Assuming equal weight distribution, the roof supports absorbed much less than 100 pounds per square inch additional loading. All steel surfaces have been painted with primer and machine gray for corrosive protection.

Power for AENFTS facility is provided by a 2000 KVA transformer mounted on the pad south of I-Bay. Its primary power of 6900 volts, 60 Hz, 3 phase, Delta is obtained from cubicle 112 in G-Bay. The transformer secondary 480Y/277 VAC, 60 Hertz, 3-phase is carried through a weatherproof copper bus duct to the motor starter center. This bus is capable of carrying 2500 amp at 480 VAC, 3-phase, four-wire, with full neutral and 50 percent internal ground. The motor starter center contains a master load breaker switch prior to further power distribution. Each motor and heater in the facility is routed through its own motor starter which consists of a circuit breaker, contactor, and overloads. Each unit is rated according to its function. A separate 30 kilowatt transformer provides power to the control console. This is 480 - 208Y/ 120 VAC minipower center. This transformer also powers the 24 VDC battery charger. The charger maintains four six volt, DEKA Model 7GCA batteries at a full charge for use in emergency situations. These batteries are rated at 75 amps for 92 minutes and are connected in series to provide 24 volts DC.

The refrigeration system is a custom designed two-stage unit built by Penjerdel Refrigeration Co. The system can provide up to 60 tons of refrigeration at 25°F and is structured to cool an ethylene glycol/water mixture to three basic temperatures. These temperatures are adjustable using the pneumatic controller but are currently set at +25°F, -15°F, and -50°F. The high stage consists of a Frick MR 190-6 compressor with a 100 HP motor. This stage is capable of reducing the glycol temperature to about -15°F. The second stage, a Frick MRI 90-12 compressor with a 75 HP motor, starts automatically and provides the additional cooling needed to reach the lower temperatures. The refrigeration unit requires about 1800 pounds of R-22 refrigerant and up to 392 gpm of cooling tower water for the condenser. Specific details for the refrigeration system can be found in the Penjerdel "Operating and Maintenance Instructions."

Cooling tower water is obtained from the 10-inch lines which run under I-Bay along the north wall of the utility tunnel. The supply and return lines were teed to enable two 6-inch lines to be brought through the floor where they can be turned off with manual butterfly valves. These lines can provide up to 650 gpm. Further distribution is provided through 4-inch lines to the refrigerator condensor and through 3-inch lines to the distilled water/tower water heat exchanger. The tower water pump control room must be notified when water will be required prior to system startup.

Instrument air is available from two sources: from the high pressure air bottles through a regulator; or from a GFE air supply available in the hall between H and I-Bays. The high pressure bottle air supply is regulated to 100 psig and directly feeds all pneumatic actuators on the nacelle simulator. Each of the valve positioners then provides further pressure reduction to 20 psig for its control air. Instrument air is also supplied to the refrigeration system for temperature and water flow control. The GFE air supply is used as an emergency backup source and is separated from the high pressure supply with a check valve. The GFE system operates at 80 psig and therefore is used only when the primary instrument air should fall below that level. The GFE system contains a water separator and two 0.9 micron filters. One is used as a particulant filter while the other is an oil filter. Each filter is monitored with a pressure differential gauge to indicate when a filter should be replaced. The separator and filter traps contain valves which allow them to be drained as the need arises.

Section III
INSTALLATION AND CALIBRATION

A. GENERAL

A number of significant work efforts were performed by subcontract. Hughes Bechtol installed the high voltage and power distribution equipment; Foreman Industries installed the plumbing, the electrical control wiring, and the pollution control equipment; and Jolar Inc. fabricated the test sections. In these cases, SRL performed system integration and performed installation verification.

B. NACELLE TEST SECTIONS

The Nacelle test section was fabricated by a local firm and all sections were tested in accordance with the instructions on the fabrication drawings. SRL engineering personnel monitored these tests and verified that no leakage or distortion occurred when the test sections were pressurized to 30 psig.

The sections were then brought to the site for assembly. When all the sections were together and lined up with the inlet and outlet flanges, a misalignment became apparent. The difficulty was identified to be with the downstream flange of the five-foot-long test section. Either the welding was incorrect or distortion occurred during the heat treating process. In either case the flange missed being perpendicular to the test section by 1/4 inch at one corner. This problem causes both an angular error at the nacelle transition section as well as a translational error due to eccentric rotation. The nacelle sections were rotated and measured at 90° intervals to quantify the magnitude of the discrepancy. It was found that the translational errors could be corrected and the angular slip ring would accommodate the angular errors. The slip ring is free to rotate within the flange mounting bolts and should be adjusted for the best fit possible. Any remaining error is then absorbed in the expansion joint.

In order to help support the duct heater assembly, an adjustable clevis was installed on the heater duct transition just inside the hazard test cell. This clevis could support the entire duct heater assembly without the supplemental support frame under the heaters. As long as that framework is available and the transition section is bolted to the nacelle test sections, the clevis is not necessary. In fact, it must be removed whenever heating tests are to be run in order to avoid limiting system expansion.

While installing the windows in the test sections, it was noted that most bolt holes would not accept the bolts or that they were not deep enough. It was determined that the holes had been tapped prior to heat treating, and that this process had distorted the holes. High tensile strength carbide taps were tried, however several were broken in the holes. Therefore, Jolar Inc. brought in other resources to use an electrical discharge machine (EDM) to clear the holes. All window holes except the top row in the middle test section nearest the wall were cleared. The remaining holes could not be reached due to clearance limitations. It was felt that if the heaters or the test section were moved at some time in the future, these could be cleared by hand.

The nacelle sump was enlarged to accommodate higher flow rates should excessive fluid build up in the exit transition section. One-inch hose and pipe now enable maximum flow through the one-inch ball valve, pump, and check valve. A supplementary drain was also added to the sensor viewing port to prevent its filling up.

C. POLLUTION CONTROL SYSTEMS

Several changes were implemented in the separator tank fill and drain plumbing in order to increase the reliability of the flow to the segregator. It was initially noted that the separator would overfill so a pressure gauge was installed on the outlet of sump pump #1. It became readily obvious that flow would regularly be lost and the discharge line would have to be drained in order to reestablish normal operation. It was felt that the only possible cause could be air entering the suction side of the pump and thus locking it up. The overflow of the separator was carefully observed and it was felt that this was not where air was entering the system. The only other possibility was the scrubber overflow line which emptied into the cross at the bottom of the tank. It was felt that this line should always have water however, this line was replumbed to discharge directly into the bottom of the separator tank. The drain was reestablished by drilling a one-inch diameter hole in the bottom of the overflow stand pipe. This hole is necessary to provide a continuous source of water to the sump pump even when the water level in the separator is below the top of the stand pipe. The hole is not however, large enough to keep the pump operating at its maximum flow rate, therefore, the outlet line must be throttled to maintain correct pump operation. This modification did correct the problem and as was later noted that substantial amounts of air were included in the scrubber overflow effluent.

PVC pipe was also installed inside the separator tank in order to direct the fresh make up water to the quench pump inlet. It is hoped that this will extend the life of the quench nozzles by keeping the strainers clean. The quench pump water pickup was cut off to enable the water inlet at a higher level inside the tank. A filter screen was placed over the inlet which can be backwashed by enabling the fill function without the quench pump being on.

The float switch on the separator tank presented numerous difficulties, both with the contacts being fused and the general level adjustment. On two occasions, the contacts were fused even though the only current draw was for input to the TI controller. The third unit has worked without difficulty. The limited travel of the switch float due to installation limitations makes the adjustment of the contacts very sensitive. The encapsulated contacts must be positioned with the set screen in such a manner as to accommodate the switch hysteresis within the movement limitations of the float.

D. CONTROL AND INSTRUMENTATION

The checkout of the AENFTS control and instrumentation systems was an activity which extended over many months and in many cases, involved a sequential process. As testing and troubleshooting indicated, interlocks and control parameters were refined and modified. This was accomplished both within the TI controller and through hardwiring of the various systems. Additional controls were added, such as the pressure switch on the output of sump pump #1 which in turn provided an electrical input to the TI controller. The controller program was modified on numerous occasions to force certain sequential or timed events to occur as required to support operational criteria and safety limitations.

The basic instrument utilized for calibration and set up purposes was a Fluke 3-1/2 Digit Digital Multimeter. This instrument had an accuracy of $\pm$0.1 percent of the reading plus one digit. The use of the 20 milliamp current generator in conjunction with the meter was used to set up the various current loops and high-limit controller set points. A Simpson Meter, Model 260, was used primarily to read AC voltage and to check circuit continuity.

Checkout of the set point controllers indicated several difficulties with the computer interface. The outputs from the analog out cards were wired for voltage outputs rather than current loop outputs which the SPCs required. This was corrected, however it was then noted that the remote input shunt resistors had been destroyed due to heat. Checking the circuits, it was found that the output with reference to the SPC ground amounted to about 200 milliamps at 30 volts. Further troubleshooting and investigation identified the need for an isolation amplifier between the computer subsystem and the SPC. Several units were tested and an Analogic MP227 Isolation Amplifier was found to provide satisfactory performance. It was also found that there is a difference in the input requirements for the two types of set point controllers, i.e., temperature versus current loop inputs. Set point controllers Nos. 1 through 8 have thermocouple inputs and require a voltage input of 0.75 to 3.8 volts, or a shunt resistor of about 200 ohms. The current loop input units, SPC-9 through 16 require a 253.16 ohm shunt resistor to provide the necessary 1 to 5 volt input.

Initial testing of the atmospheric blower indicated a lack of control of the blower back pressure valve (VP-1). After reviewing the required performance parameters, the SPC was changed to a reverse acting unit. In this way, as the input increases beyond the set point the back pressure valve would open (the output also increases) in order to reduce the input. It should be noted that the CHILL AIR (SPC-8) set point controller is also reverse acting.

A review of the atmospheric blower from venturi data identified a major calibration error. The flow transducer (PT-2) was specified at 58.88 inches H_2O based on preliminary manufacturers data. The as-built unit however, had a much lower indicated pressure differential for the corresponding 16 pound mass flow. Flow testing indicated that inlet temperatures would approximate 100°F when operating the blower with 36 inches H_2O static pressure. These conditions then were used in the calculations for the flow which resulted in 16 pounds per second mass flow being equivalent to 32.05 inches H_2O differential. In order to make the output of the signal conditioner match the new pressure differential the gain of the signal conditioning amplifier was changed to 1 mV/Volt by replacing resistors as specified and provided by Sensotec, Inc. This then would enable the 10.921 millivolt transducer output to be within the adjustable range of the full scale output span calibration control.

The transducer was calibrated by connecting a vertical column of colored distilled water. The coloring was added to provide both a clearly visible water column and to reduce the wetted surface tension of the water. Several iterations were necessary to set up the zero and the span. The present setting for channel 2 of the signal conditioner is 4 to 20 mA out equals 0 to 10.921 mV out of the transducer which is equivalent to 0 to 16 pounds mass flow.

E. FACILITY INTERFACE

The refrigeration system was started by a field service representative from Penjerdel Refrigeration Co. The high stage compressor started satisfactorily after several freon leaks were repaired. The low stage however, spewed oil out the front bearing seal. It was decided that this would be repaired after the insulation had been installed and the entire system could be tuned. However, due to delays with the installation, the repairs were initiated without insulation. Replacing the front seal on the low stage corrected that difficulty, however, the high stage would not maintain oil pressure after start up. Scored bearings on the crank shaft were the cause of the problem and these were also replaced. It was never determined what caused the bearings to fail however, no further problems have been encountered. The units were never run in the AUTO position and some limit controllers may need to be adjusted when this is done.

The compressor suffered a number of major failures after appearing to run successfully for several weeks. The first indication of a problem occurred when the check valve failed. The problem was an internal failure of the "O" ring which was corrected by replacing the ring. Thereafter, the pressure relief valves began operating due to an accumulation of condensate due to a faulty condensate valve. Repair however, only exposed a third stage overpressure condition which could not be resolved. The Ingersoll-Rand service representative found some damage on the fourth stage cylinder head. He replaced that stage and the compressor functioned normally. The compressor was operated overnight and in the morning substantial amounts of oil were found on the floor and the surrounding equipment. When the service representative returned he disassembled the interstage condensors to try to locate the source of oil. Only the fourth stage seemed suspect. The fourth stage was replaced and the system again ran overnight. By the following morning, the system had shut down due to low oil pressure with substantial amounts of oil again on the floor and equipment. While performing further tests with the system under load, the fourth stage piston head was blown off. The service representative then again consulted with the plant and it was decided to ship the unit to the factory. The factory rebuilt the unit and after twenty hours of operation experienced the same difficulties. That unit was then disassembled and inspected while a new compressor was being built. The inspections determined that the fourth stage cylinder base was misaligned by .004 inches. This in turn caused excessive ring wear which then precipitated the problem.

The new compressor was installed in the I-Bay only after extensive modifications to air system had been implemented. This included installing a receiver bottle between the compressor and the dryer to catch any further oil carry over and to smooth out the pressure pulsations of the compressor. After the dryer, two 0.9 micron filters were installed. One acts as a particulate filter while the other is an oil filter. In addition, the control system was modified to allow the dryer to turn on ten minutes before the compressor. In this way the dryer will have achieved its operating conditions prior to handling any compressed air.

A check valve was also installed in the high pressure distribution line just downstream of the compressor inlet. This will prevent damage to the compressor or bottle farm should compressive detonation occur. The loop of high pressure air line under the rear door was cut and then flanged to allow its future removal. A condensate drain was installed at the bottom of the loop and a hand valve was welded into the line in order to isolate the bottler farm from the rest of the system.

An associated task which required major work efforts was the cleaning of the lines which had been contaminated with oil. The system was broken down into sections and a water/detergent mixture was circulated. The nacelle inlet and duct heaters were cleaned by hand as were the bottle farms; that is a spray bar was fabricated which was then lowered into each bottle. The effluent was then removed at the drain in the bottom of the bottle. Effluent samples were taken throughout the cleaning process which were analyzed for their oil and detergent content.

During the months that the compressor was down, no tests whatsoever would have been possible without instrument air. Since the high pressure air from the bottle farm was not available an alternate source was found by tapping into the building air supply in the hallway between H-Bay and I-Bay. The operating pressure for this system is only 80 psi versus the normal 100 psi from the high pressure air system. Therefore, a check valve was installed to prevent cross flow.

In addition, a water trap and oil and particulant filters were installed to ensure that the air was both clean and dry. In this way, should the high pressure air fail to provide instrument air, a backup system can be used to complete an orderly shutdown as well as provide an alternate source for general use purposes.

Section IV
TEST RESULTS

The testing that was performed on the Aircraft Engine Nacelle Fire Test Simulator (AENFTS) consisted of two distinctive parts. The first was subsystems tests, in which each individual component was checked for correct rotation and functioning. Then system tests were performed in accordance with the Research Development Test Plan dated March 1979. This plan was developed to demonstrate the capabilities of the entire system to meet all design performance/safety requirements; demonstrate and optimize all operating and emergency procedures; and to train an Air Force operating team. The following discussion presents the results of these tests in order in which they are presented in the TEST PLAN.

A. TEST 1 - ATMOSPHERIC BLOWER CONTROL

Test 1A called for setting up HLC-16 to control the limits of the performance of the blower. HLC-16 is a dual set point unit which trips at 32 inches H_2O and 38 inches H_2O. Any back pressure outside these limits will start the blower shutdown timer. The normal setting for the back pressure should be 36 inches H_2O.

Test 1B involved incremental increases in flow through the test section. This was shown to be controllable, however at about ten to eleven pounds mass flow, a loud resonance developed in the expansion joint. In order to avoid acoustic vibration fatigue, further operation in this performance regime was avoided until a sleeve could be built to prevent future vibrational effects.

B. TEST 2 - AIR SYSTEMS

This series of tests was designed to establish operating limitations and check system performance of the high and low flow systems.

Air Flow (SPC-13) (PPS)	0	1.4	2.5	3.7	4.9	6.1	7.3	8.4	9.8
Air Flow (DPM-29) (PPS)	0	0.9	2.0	3.0	4.3	5.5	6.8	7.8	Disc Rupture
Nozzle Temp (DPM-31) (°F)		36	39	43	48	50	51	51	
Test Inlet Temp (DPM-23) (°F)		70	69	69	67	65	61	60	
Air Storage Press (DPM-32) (psi)	1933	1985	1873	1850	1804	1738	1680	1590	
Test Inlet Press (DPM-24) (psia)		14.2	14.4	14.9	16.4	19.3	22.1	25.7	

Test 2A was performed with the limits controls of HLC-18 set for 5.4 mA 15.2 mA (1.4 pps and 11.2 pps, respectively). The data taken during the test as performed on 5 September 1979 is presented below.

This particular test sequence was terminated with a blown rupture disc in the high pressure air inlet system. As can be seen, the test inlet pressure exceeded the design rating and the rupture disc burst during the step increase to 9.8 pounds of flow. This overpressurization was due to the use of the ten-inch valve for nacelle pressure control which bypasses the air through the ejector. The ejector in turn is not capable of handling the high flow rates and the pressure therefore backs up into the nacelle test section. Although no specific data was taken of the nacelle outlet pressure (DPM-20) it was noted that the pressure indications followed those of the nacelle inlet pressure and were generally within 0.2 psia of the inlet pressure settings.

After repair of the rupture disc, the test was rerun to confirm the above readings. This was done but the test was terminated prior to reaching a nacelle inlet pressure of 24 psia.

During all the above testing, SPC-11 was set to about 14.5 psia. The second part of the test involved setting the high flow to 3.5 lbs/sec. SPC-11 was then used to control the nacelle test inlet and outlet pressure. A one psia step was used to vary the nacelle pressure from 15.3 to 24 psia. The test inlet and test exit pressure increased in accordance with the settings of the SPC-11. No hunting or pressure oscillations were evident.

C. TEST 3 - EXHAUST SYSTEMS

The exhaust blower high limit controller was adjusted during subsystem start up. Initial tests indicated only limited control of the exhaust blower back pressure. At the time this was run however, the nacelle test section was in various stages of assembly, so data acquisition or control had limited meaning. Additional tests are required to resolve the outstanding issues.

D. TEST 4 - NACELLE AIR CONDITIONING

The nacelle air heating was checked and set up using the atmospheric blower. Initially HLC-10, 11, 12, 13, and 14 were set to 500° and the blower flow was set to 8 lbs/sec. The test inlet pressure (DPM-24) was 14.3 or 14.1 psia throughout the test. The duct heaters were then set for 200°F by SPC-7. After about fifteen minutes the nacelle inlet temperature as measured by DPM-23 was 139°F and 137°F as measured by the A and B channel, respectively. With the set point at 300°F, inlet temperature balanced at 200° and 206°F, respectively, while with the set point at 400°F, the maximum inlet temperature achieved was 263° and 264°F. Also at this time it was noted that the HLC's would occasionally trip due to overheating on the sheath temperatures. The blower flow was then reduced to 4 lbs/sec however, the inlet temperatures only increased to 269° and 292°F with the set point at 400°F. The ground of the thermocouple was checked however, no difficulty was noted. The characteristics of the duct heaters were reviewed and it was noted that the sheath temperatures could withstand 1075°F. The HLCs were therefore raised to 1000°F, and although the overheat tripouts stopped, the output temperature did not increase. All six test section flow thermocouples confirmed the nacelle inlet temperature and were always within ten degrees of the inlet temperature. Further testing must be performed to resolve this discrepancy.

E. TEST 5 - TEST SECTION HEATING

This section of the tests was used to prove that adequate nacelle heating temperatures could be attained and that they could be controlled. Initially all the appropriate high limit controllers were set up. HLC-1, 2, and 3 were set to 200°F while HLC-4, 5, 6, 7, 8, and 9 were set to 1600°F.

Heating tests with flow were run first in order to provide some cooling protection should any problems be encountered. Atmospheric blower flow was set at three lbs/sec. The data in Table IV-1 was then acquired. Data points were taken about every fifteen minutes during which the last five minutes were all at a stabilized temperature. All six heating zones were heated simultaneously to minimize thermal stress during the initial heating efforts.

The results of the tests indicate good control of the test temperatures, however the actual temperatures obtained were a function of the location of the thermocouple. The closer the thermocouple is to the interconnecting flange, the cooler it appeared. Zone 1 was always cooler which may be due to its proximity to the unheated inlet section.

A number of thermocouples failed during these initial tests and were repaired. Repair of those on the engine side surface however required lifting the heaters out of the way which was a lengthy process. Reheating to 800°F however, proved the effectiveness of the repairs as all thermocouples were then good.

Testing of heating control during no flow conditions was done after heating control had been established and verified. Heating to 1500°F produced the following results:

TABLE IV-1
TEST SECTION HEATING

ATMOSPHERIC FLOW - 3 lbs/sec

Zone 1								
Set Point (°F)	350	500	650	800	1000	1200	1400	1500
Engine Side Temp A (°F)	258	340	450	553	729	908	1120	1245
Engine Side Temp B (°F)	------	BAD	------	------	------	1181	1250	1100
Air Flow Temp (°F)		96	100	97	109	125	154	188
Nacelle Side Temp A (°F)	83	120	131	124	215	281	403	541
Nacelle Side Temp B (°F)	83	121	131	125	216	281	397	531
Zone 2								
Set Point	350	500	650	800	1000	1200	1400	1500
Engine A	338	490	642	792	1009	1230	1433	1531
Engine B	286	405	529	654	879	1095	1298	1404
Air Flow		99	103	101	115	136	174	216
Nacelle A		120	135	122	236	311	448	599
Nacelle B		118	132	121	235	310	449	592
Zone 3								
Set Point	350	500	650	800	1000	1200	1400	1500
Engine A						1261	1230	1230
Engine B	338	483	644	800	1012	1232	1431	1531
Air Flow		98	103	102	118	140	179	220
Nacelle A			161	155	279	365	512	653
Nacelle B			157	149	270	356	507	636

TABLE IV-1 (continued)

Zone 4								
Set Point (°F)	350	500	650	800	1000	1200	1400	1500
Engine A		484		793	1003	1218	1426	1527
Engine B		349		586	879	1320	1213	1229
Air Flow				107	123	147	193	240
Nacelle A				138	261	350	503	1651
Nacelle B				137	263	357	517	657
Zone 5								
Set Point	350	500	650	800	1000	1200	1400	1500
Engine A	278	377	512	647	864	1065	1279	1402
Engine B	354	500	661	808	1020	1223	1435	1540
Air Flow		102	109	110	128	152	194	239
Nacelle A		130	150	134	281	375	531	672
Nacelle B		129	148	133	274	366	520	652
Zone 6								
Set Point	350	500	650	800	1000	1200	1400	1500
Engine A	353	500	659	806	1013	1232	1433	1537
Engine B	284	410	540	654	877	1088	1285	1392
Air Flow		107	114	114	134	156	195	1233
Nacelle A		500	666	813	1024	1233	1441	1548
Nacelle B		120	143	122	255	343	488	610

Nacelle Zone Heating - No Flow

Zone	1	2	3	4	5	6
Set Point (°F)	1500	1500	1500	1500	1500	1500
Engine Side Temp A (°F)	1100	1530	----	1530	1415	1537
Engine Side Temp B (°F)	1527	1302	1533	1237	1539	1401
Air Flow Temp (°F)	612	600	551	573	610	662
Nacelle Side Temp A (°F)	753	753	707	559	751	----
Nacelle Side Temp B (°F)	747	715	680	548	734	723

The addition of duct heating was tested by establishing atmospheric blower air flow at three lbs/sec and then heating the nacelle to 1500°F. When these temperatures stabilized, the duct heaters were turned on with the set point controller set to 400°F.

Heating Zone	1		2		3		4		5		6	
	Flow	Flow + Duct Heat	Flow	Flow + Duct Heat	Flow	Flow + Duct Heat	Flow	Flow + Duct Heat	Flow	Flow + Duct Heat	Flow	Flow + Duct Heat
Set Point (°F)	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Engine Side Temp A (°F)	1150		1530	1531	----	----			1245	1379		1536
Engine Side Temp B (°F)	1240	1300	1411	1320	1527	1535			1360	1541		1395
Air Flow Temp (°F)	287	385	294	396	275	375			254	390		396
Nacelle Side Temp A (°F)	694	581	716	643	641	615			686	656		1120
Nacelle Side Temp B (°F)	666	579	654	611	606	581			607	597		604
Test Inlet Air Temp (°F)		286		286		286				286		286

This test brought about some interesting results. Zone 4 data was not taken because temperature control of that zone failed due to thermocouple failure. Certainly this did have some impact on the temperature distribution of the adjacent zones. Interestingly, the air flow with heat reduced the nacelle side temperatures. At this time this phenomenon is not understood and will require further investigation when the duct heater can achieve 400°F on the inlet. While getting the system up to temperature only two intermediate points were utilized: 800°F and 1100°F. The engine side temperatures were stabilized at 800°F within fifteen minutes of the starting time. The other increments were given similar lengths of time to stabilize in order to minimize thermal stresses.

F. TEST 6 - COMBUSTIBLES TESTING

This test included the hydraulic fluid and fuel sides of the fluid dispensing cart in order to verify system operation. The fluid dispensing cart was tested independent of the rest of the nacelle since some necessary interconnections were not available. The only fluid used was water and thus all heating was limited to 190°F for fluid temperature. The pressure vessel shell limitation was set at 220°F.

The heating process was relatively slow and the 190°F temperature was reached only after one-half hour, but the temperature then overshot the limit by 20°. It would appear that the vessel shell temperature should be set very close to the desired fluid temperature to minimize the overshoot.

The testing of dump and injection system was performed with the fluid lines tied down where they could be observed to verify their operation. These tests were conducted successfully.

Section V
CONCLUSIONS

While the tests performed were relatively successful, they did point out several problems relative to the maintenance of the system, i.e., the repair and maintenance of the nacelle thermocouples. In addition, further testing will be required to resolve problems which were identified by the test already completed, i.e., the duct heaters only achieving 260° temperatures.

The atmospheric blower system is fully operational and functions well with all control limits in place. The high and low flow systems require additional testing. The exhaust system was also tested and found to be fully functional.

The Aircraft Engine Nacelle Fire Test Simulator was transferred to the Air Force during February 1980 with the facility operational contractor to perform additional simulator checkout prior to initiating specific test programs. This simulator will provide the Air Force with a unique testing capability.

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